Lower Colorado River
Multi-Species Conservation Program

Balancing Resource Use and Conservation

Population Status and Distribution of Razorback Suckers and Bonytail Downstream from Palo Verde Diversion Dam

2020 Annual Report

August 2021

Work conducted under LCR MSCP Work Task C64

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U.S. Fish and Wildlife Service
National Park Service
Bureau of Land Management
Bureau of Indian Affairs
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Lower Colorado River Multi-Species Conservation Program

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2020 Annual Report

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ACRONYMS AND ABBREVIATIONS

AIC_c	Akaike's information criterion adjusted for small sample size
C	capture
Center	Southwestern Native Aquatic Resources and Recovery Center Dexter, New Mexico
CI	confidence interval
FDX	full duplex (passive integrated transponder tag)
GAM	generalized additive model
HDX	half duplex (passive integrated transponder tag)
kHz	kilohertz
km	kilometer(s)
LCR	lower Colorado River
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
M	mark
MAL	months at large
M&A	Marsh &Associates, LLC
m	meter(s)
mg/kg	milligram(s) per kilogram(s)
mm	millimeter(s)
MS-222	tricaine methanesulfonate
PIT	passive integrated transponder
R	recapture
RM	river mile
SUR	submersible ultrasonic receiver
SY	study year
TL	total length
USFWS	U.S. Fish and Wildlife Service
UTM	Universal Transverse Mercator

Symbols

>	greater than
≥	greater than or equal to
>	less than
%	percent
®	registered

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Executive Summary

This is the fourth year of the current 5-year project to monitor the population status and distribution of razorback suckers (*Xyrauchen texanus*) and bonytail (*Gila elegans*) in the lower Colorado River downstream from Palo Verde Diversion Dam and upstream of Imperial Diversion Dam (study reach). Based on records in the Lower Colorado River Native Fish Database, 10,810 razorback suckers and 5,044 bonytail were stocked into backwaters and the main channel of the study area in La Paz County, Arizona, and Riverside County California, from October 2019 through April 2020. In an experimental release, 400 bonytail were implanted with 32-millimeter (mm), 134.2-kilohertz (kHz), half duplex passive integrated transponder (PIT) tags. All other fish released were implanted with 12-mm, 134.2-kHz full duplex PIT tags.

Up to 20 portable remote PIT tag sensing units (scanners) were distributed throughout backwaters and the main channel for 5 days during each month from October through March. During the peak razorback sucker spawning season (January – February), PIT scanners were deployed for 10 days each month. Scanning effort in the river channel was increased from the last sampling year during the active sample period (October 1, 2019, to March 31, 2020) to identify aggregation or spawning sites outside of backwater habitat and to contact individuals during spawning. Two, semipermanent scanners were placed in culverts to monitor dispersal through and out of backwater habitat. These culvert scanners ran continually from January through April 2020.

Marsh & Associates, LCC, deployed PIT scanners for 17,623.1 hours in the study year (SY). Marsh & Associates, LCC, and the Bureau of Reclamation contacted 3,194 razorback suckers and 347 bonytail through combined efforts. There were 923 razorback suckers contacted in the SY that had been released more than a year prior to their most recent contact; zero bonytail contacts fit this criterion. A total of 989 unique PIT tags with records in the Lower Colorado River Native Fish Database were contacted in the mainstem during study year 2020. Most of the river contacts, 919 (92.9%), were at the C7 gravel bar aggregation site (915 razorback suckers and 4 bonytail). No bonytail were contacted during the marking period (January 1 to February 28, 2019) were contacted again in the capture period (October 1, 2019, to April 30, 2020), so no population estimate was possible. The razorback sucker population estimate for 2019 was 359 (95% confidence interval [CI] 342 to 375), more than double last year's estimate of 147 (95% CI 123 to 171).

The total length at release and release location are significant predictors of monthly scanning probability for razorback suckers based on a generalized additive model analysis of PIT scanning contact data. In general, scanning probability was higher for greater TL at release, and scanning probability was highest for A10 upper releases. Razorback sucker adult survival in the study

reach was estimated to range from 0.511 to 0.848 annually based on a robust mark-recapture analysis. Contact rates (probabilities) varied from 0.013 to 0.801, with the highest values for each year occurring during peak spawning in January and February. Preliminary estimates of adult survival rates range from low to comparable rates in other reaches, but more data are needed for reliable survival estimates.

Twenty subadult razorback suckers and 20 subadult bonytail were implanted with short-term (3-month) acoustic telemetry tags to examine dispersal patterns immediately following release. Ten adult razorback suckers were implanted with longer-term (36-month) tags to monitor long-term dispersal. All 10 of the razorback suckers implanted with long-term tags were acquired by electrofishing over the C7 gravel bar in the river.

Throughout the SY, manual tracking of acoustic tags was conducted in backwaters to supplement submersible ultrasonic receiver data used to track dispersal and to identify stationary tags. Tracking also was conducted in the main channel throughout the SY, and four razorback suckers were contacted at the C7 gravel bar in the main channel, and one subadult was contacted downstream from C7; one subadult bonytail also was contacted downstream from C7. The maximum dispersal distance of any acoustic-tagged fish was 100.6 kilometers by a subadult razorback sucker released in October 2019.

A small but growing population of razorback suckers has been established in the study reach. There now are two known razorback sucker spawning aggregations in the reach, the C7 gravel bar in the main channel of the river and the A10 upper spawn site at the southernmost portion of A10 upper. These two sites appear to consist of different aggregations of adult fish, and continued scanning of each site should allow for better estimates of adult survival. Preliminary analyses of scanning probabilities for razorback suckers suggest there is much higher survival for larger fish, particularly for those > 400 millimeters TL at release.

Bonytail data continue to be too sparse for formal analyses likely due to high post-stocking mortality.

INTRODUCTION

Razorback suckers (*Xyrauchen texanus*) and bonytail (*Gila elegans*) are listed as endangered by the U.S. Fish and Wildlife Service (USFWS). Wild populations are extirpated from the lowermost Colorado River, and the two species remain in this portion of their native range only through intensive stocking. The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) has been stocking fishes into the lower Colorado River (LCR) between Parker Dam and Imperial Diversion Dam, LCR MSCP River Reaches 4 and 5, since 2005. The program has a planned stocking goal of 6,000 razorback suckers and 4,000 bonytail per year into Reaches 4 and 5 for 45 years, with all fishes being ≥ 305 millimeters (mm) in total length (TL). Beginning in 2018, an additional 4,000 bonytail per year were scheduled to be stocked to support a 10-year period of intense research and monitoring (Bureau of Reclamation 2015). An additional 6,000 razorback suckers were scheduled to be stocked for a 10-year period starting in 2019. All fishes are released with a 134.2-kilohertz (kHz) passive integrated transponder (PIT) tag.

Previous research and monitoring efforts in the study area (2006–08) estimated annual survival of razorback suckers at < 30%, and no estimate was available for bonytail due to low recapture rates (Schooley et al. 2008). A prominence of piscivorous fishes and birds and a high incidence of injuries from attempted avian predation were associated with low post-stocking survival of both species. The results were based on trammel net and electrofishing data, and recapture rates outside of release backwaters were low (less than 1% of total fishes released). The current research and monitoring efforts are based primarily on remote PIT tag sensing, which may provide higher contact rates while eliminating stress and mortality due to capture and handling.

The current project has six primary objectives:

1. Contact razorback suckers and bonytail using mobile remote PIT tag sensing units capable of detecting full duplex (FDX) 134.2-kHz tags and deployable in backwater, slack water, and riverine sections of the Colorado River.

2. Conduct eight monitoring trips across multiple release sites and habitat types within Reach 4 of the LCR MSCP from October through March of each year.

3. Conduct broad scale multi-year telemetry monitoring on 10 resident adult razorback suckers per year to determine relative dispersal, seasonal movements, and preferred habitat types.

4. Conduct broad-scale telemetry monitoring of 20 subadult razorback suckers and 20 subadult bonytail each year to determine relative dispersal and preferred habitat types.

5. Assimilate and summarize all Reach 4/5 razorback sucker and bonytail contact data collected by other Federal and non-Federal entities into mark-recapture population estimates for each species with 95% confidence intervals (CIs).

6. If data are adequate, use mark-recapture modeling to provide estimates for adult survival (with 95% CIs) and assess its dependence on a variety of factors (i.e., size at release, location of release, and season of release) for all razorback suckers and bonytail released since 2005. If data are inadequate for a model comparison assessment of all factors, use exploratory analyses to identify their potential relationship to scanning contact rates (e.g., with graphs and/or a correlation analysis).

Study Area

Reach 4 of the LCR MSCP planning area extends 104 river miles downstream from Parker Dam at River Mile (RM) 192 to the southern end of the Cibola National Wildlife Refuge at RM 88. Reach 5 continues from there 38.8 river miles downstream to Imperial Diversion Dam at RM 49.2 (figure 1). The focal area of this study, or study reach, is from Palo Verde Diversion Dam north of Ehrenberg, Arizona, downstream approximately 45 river miles to Walters Camp, California. Fishes were released into one or more of the five focal backwaters within Reach 4: A7 upper, A10 upper, A10 lower, C7 McIntyre Park, and C10 Ehler's or directly into the Colorado River (figure 2). All backwaters are connected to the main channel via a culvert or boat-accessible channel (figure 3).

METHODS

Passive and active remote sensing technologies were used to contact razorback suckers and bonytail in backwater, slack water, and riverine sections of the LCR. Passive sampling was achieved using an array of submersible ultrasonic receivers (SURs) and remote PIT tag sensing units (PIT scanners), while active sampling was conducted from a boat using a directional or towable omnidirectional hydrophone. Acoustic tags were surgically implanted into 20 hatchery-reared subadult razorback suckers and bonytail, and 10 adult razorback suckers that were electrofished from a gravel aggregation site on the Colorado River near the river access point of C7 McIntyre Park at UTM 11 S 726450 E 3711303 N, following the methods of Karam et al. 2008 and Mueller et al. 2000. Telemetry and remote

MSCP Reach 4/5 Lower Colorado River

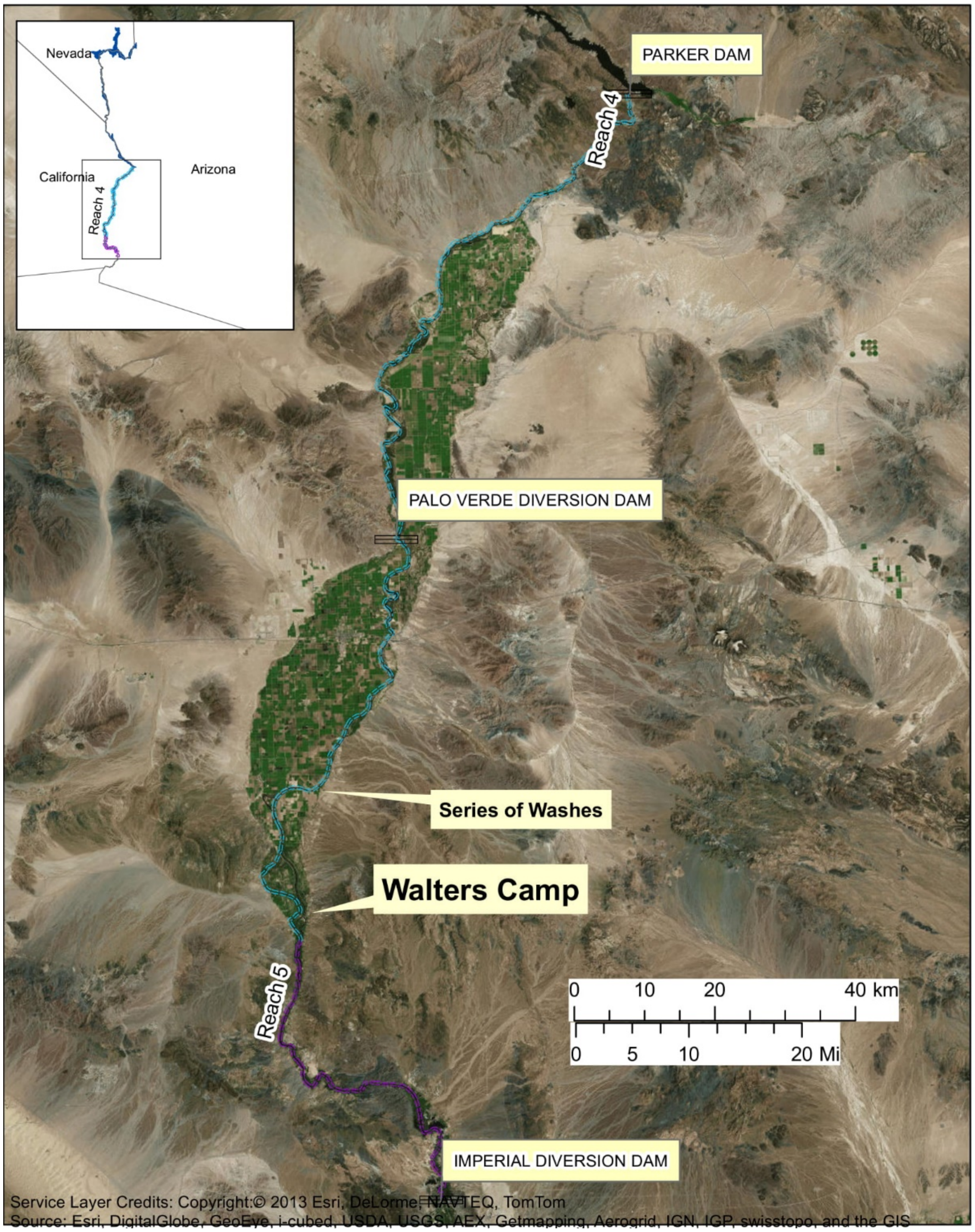

Figure 1.—LCR MSCP Reaches 4 and 5 on the LCR, Arizona and California.
Reach 4 (light blue) begins downstream from Parker Dam and continues downstream to the southern border of the Cibola National Wildlife Refuge. Reach 5 (violet) begins at the adjoining northern border of the Imperial National Wildlife Refuge and continues downstream to Imperial Diversion Dam.

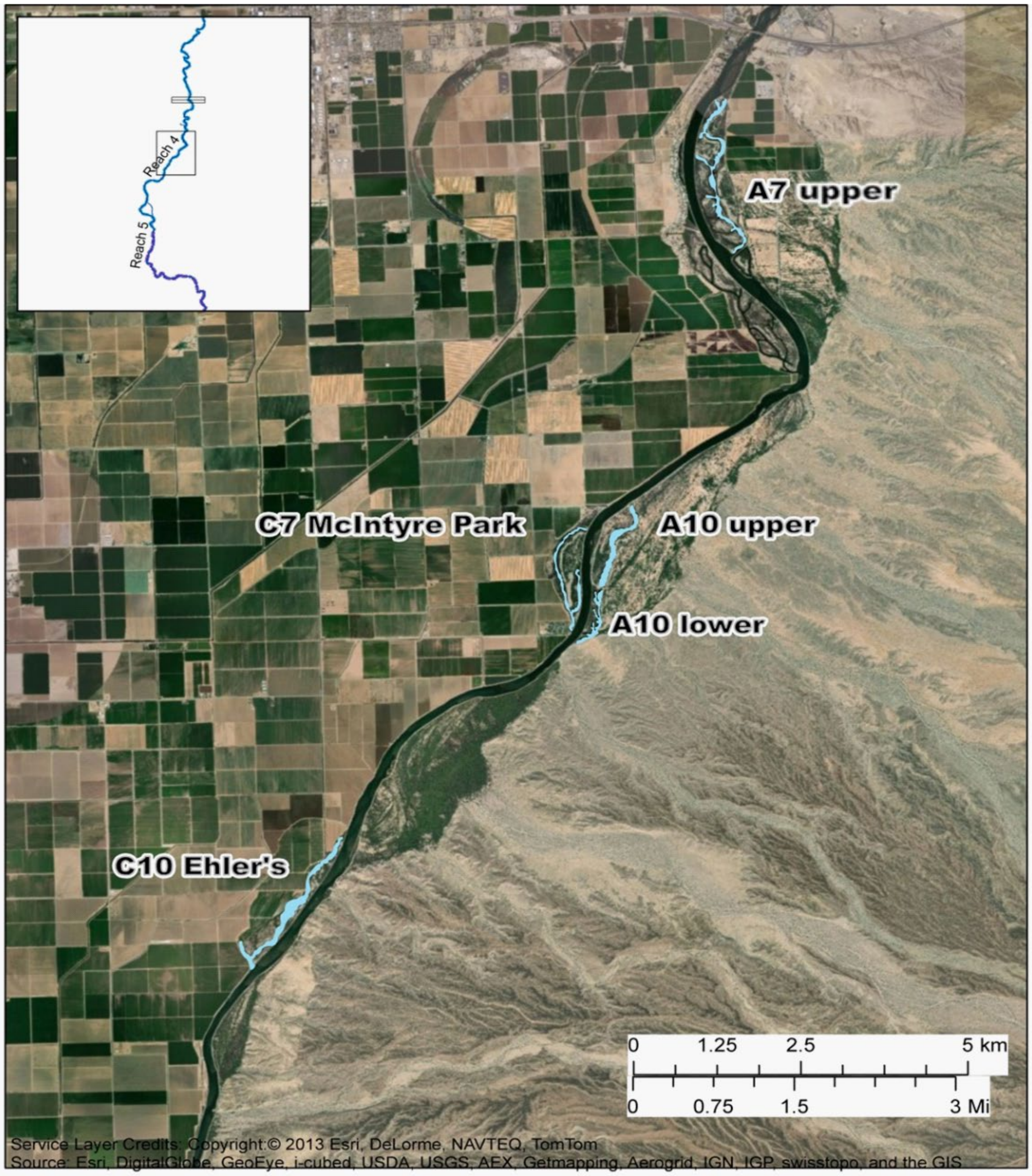

Figure 2.—Study backwaters in LCR MSCP Reach 4 on the LCR, Arizona and California.

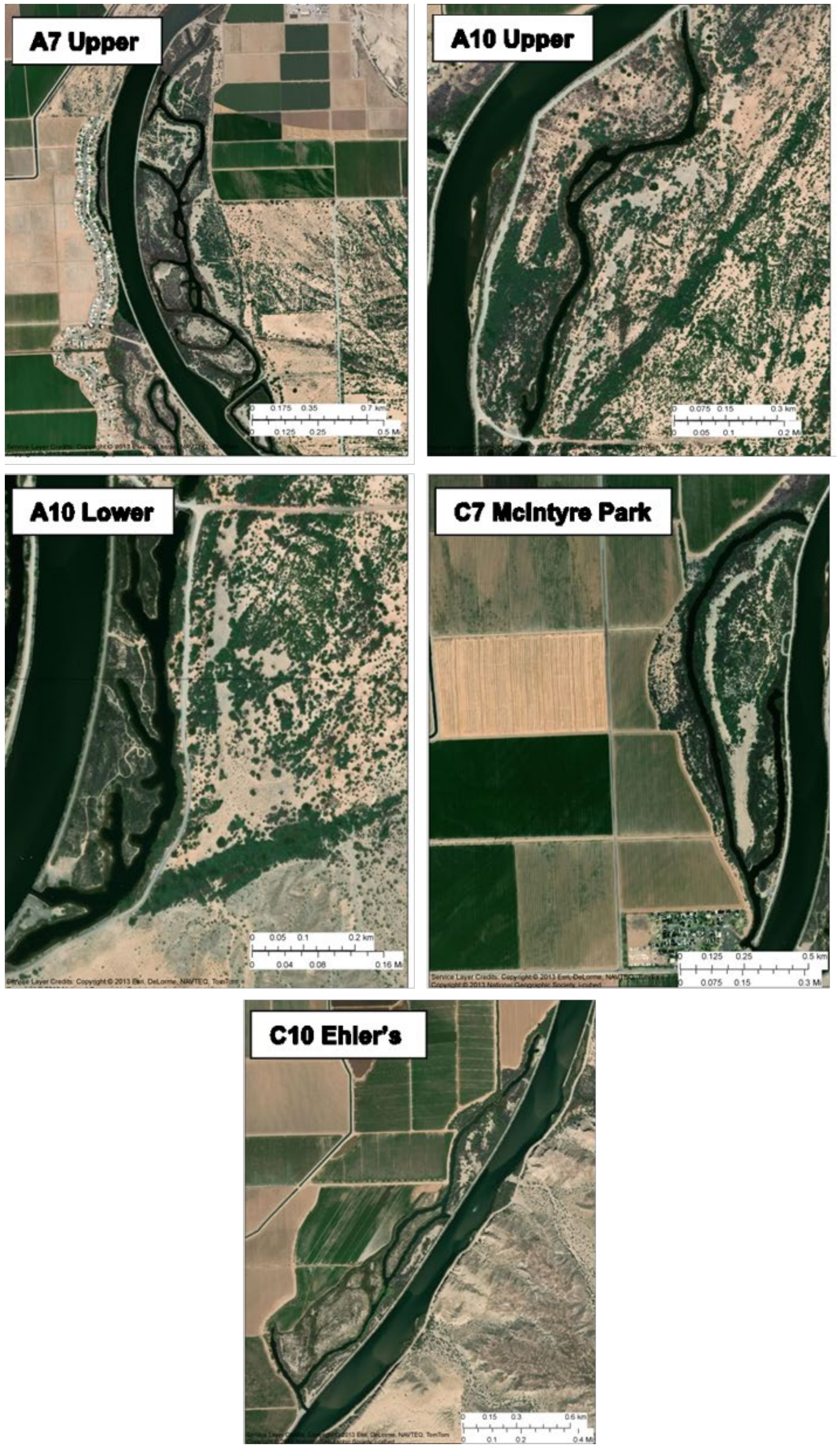

Figure 3.—Aerial imagery of five backwaters in LCR MSCP Reach 4, LCR, Arizona and California.
These backwaters were the focal point of release and monitoring efforts during the SY.

PIT tag sensing data were grouped by study year (SY) based on the fiscal year schedule (e.g., October 1, 2016, to September 30, 2017, is SY 2017). Unless otherwise stated, previous SY data in this report represent the entire SY, and current SY data were restricted to the active sampling period, through April 2020, to allow adequate time for data analyses.

Releases

Releases of razorback suckers and bonytail during SY 2020 were spatially and temporally distributed to accommodate an analysis of factors influencing post-stocking survival (objective 6). At least one stocking per season (autumn, winter, and spring) was planned, dependent on the availability of hatchery fishes and crew for PIT tagging fishes prior to release. Five backwaters were identified as primary stocking locations: A7 upper, C7 McIntyre Park, A10 upper, A10 lower, and C10 Ehler's (see figures 2 and 3). Fishes released into backwaters have immediate access to cover, which is thought to provide a relative advantage compared to the main channel, where cover is sparse and the current also is faster. All backwaters provide access to the main channel. Release sites were moved upstream and further from the river connection point within each backwater where possible compared to release sites in SY 2017 to promote an acclimation period in the backwaters rather than fish contacts being lost in the main channel immediately after release.

Telemetry

Throughout the course of SY 2020, 15 to 20 SURs were distributed concurrently throughout the study area (figure 4), an increase from previous years (12 to 17 SURs). Sites were selected to segment the main channel as best as possible to determine movement and location most accurately. All SURs deployed throughout the study area were attached to a camouflaged rope and connected to a 6-meter (m) galvanized cable that was connected to secure on-shore habitat (e.g., a tree root). Cable was used to mitigate abrasion caused by waves and current on rocks in the river. Weights were attached to the cable and SUR to ensure the SUR remained completely submerged in the water column. Each SUR had a battery life expectancy of 8 months and was programmed to scan continuously with a detection range of 200 m.

At least one SUR was deployed in each major backwater (A10 upper, A10 lower, A7 upper, C7 McIntyre Park, and C10 Ehler's). The remaining SURs were spaced out in the river from Hidden Beaches Resort (RM 126) to Walter's Camp (RM 88). Several SUR "gates" were put in place at the end of the season, where

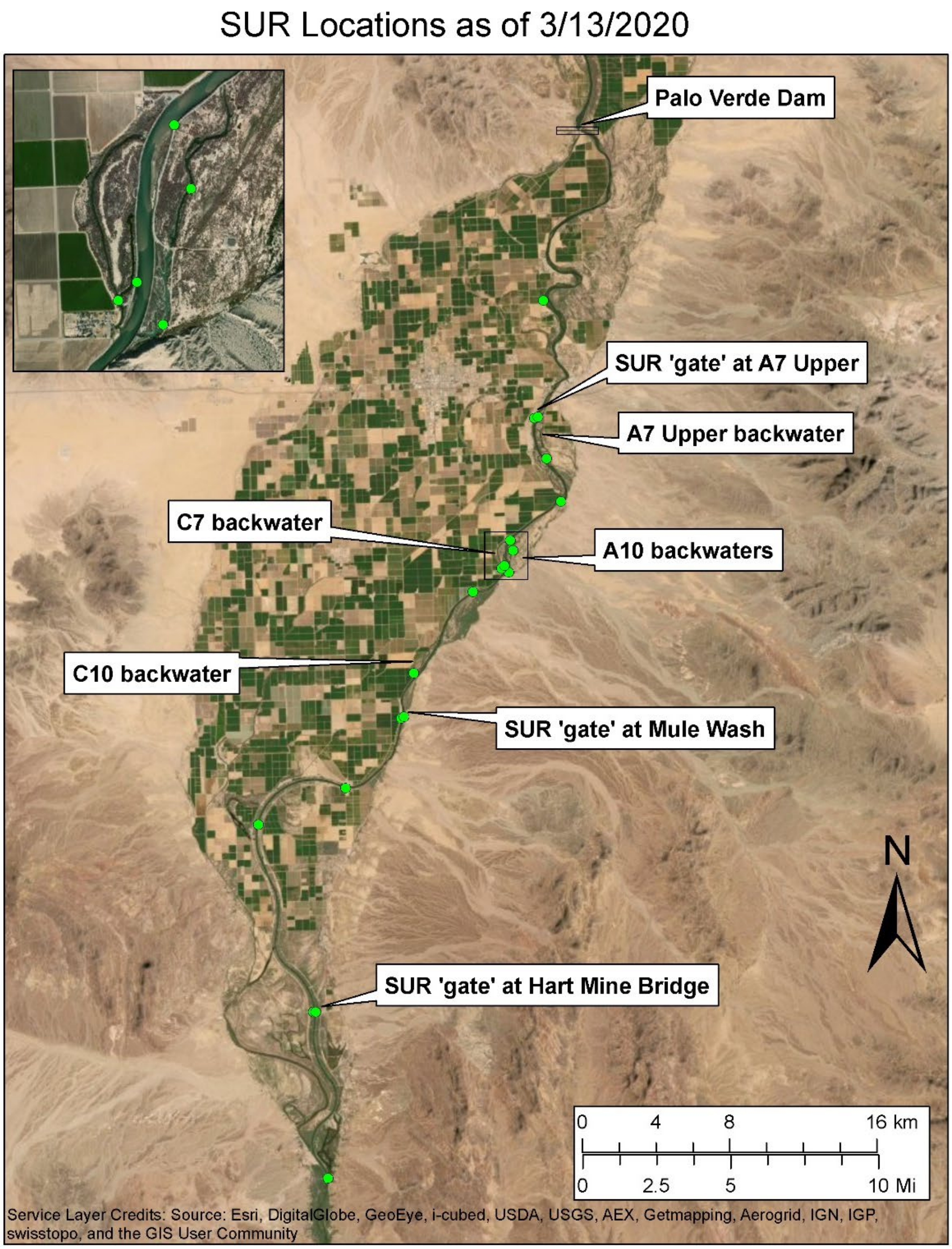

Figure 4.—Location of SURs deployed in the main channel and backwaters in Reach 4, LCR, Arizona and California.

there was one SUR deployed on each side of the main channel so that a tagged fish would be more likely to be contacted by at least one SUR when passing the gate. Gates were put in place near the upstream and downstream limits of the main study area to better assess whether telemetry fish were leaving the study area. Another gate was put in place at one of the washes downstream from C10 Ehler's, the furthest downstream backwater.

All SUR data were downloaded once every trip. In months when two trips occurred in consecutive weeks, SUR data were downloaded once during the span of the 2 weeks. Confidence levels defined by the number of detections within a timed window were calculated using Sonotronics SURsoft Stand Alone Data Processing Center software. The software calculates a confidence level between 1 and 5 for each contact (1 designating the lowest level of confidence and 5 the highest). Two detections at the correct interval and frequency within an hour were given a confidence level of 5. Only records from SURs with a confidence level of 5 were included in the analysis; others were excluded but retained in the database. Records with a confidence level of 5 also were removed from analyses when it was clear that background noise was the source of the acoustic signal and spurious record. In these isolated cases, multiple records across all frequencies with the same interval were recorded in the raw data file, which indicated that an environmental noise was present. In several cases, this was verified by a tag being recorded prior to release of the acoustic-tagged fish. Data were imported into a Microsoft Access® database used for managing fish contact histories and SUR locations.

Active tracking was conducted with a directional (Model DH-4, Sonotronics, Inc., Tucson, Arizona) or omnidirectional towable (Model TH-2, Sonotronics, Inc.) hydrophone and receiver. The receiver was manually set to specific tag frequencies corresponding to each tagged fish. Active tracking took place in backwaters throughout the SY when time permitted, with a special focus on the spawning season. As in SY 2019, additional effort was made this year to manually track acoustic-tagged fishes in the main channel.

When the towable hydrophone was used, boat speed was maintained at about 10 kilometers per hour (6 miles per hour) or slower to reduce noise interference from the engine and to allow the device to scan for multiple frequencies within a signal's potential detection range. Once a fish was detected using the towable hydrophone, the directional hydrophone was used to triangulate its location, and then an underwater dive receiver was used to pinpoint within 5 m the location of the fish. The 5-m estimate is based on previous tag recovery operations. When the gain on the dive receiver was set to the lowest setting, the acoustic signal from the tag was barely audible, and the recovered tags were always within 5 m of the location where the tag was detected using this setting.

Surgery

All surgeries followed established procedures. Hatchery-reared, subadult razorback suckers and bonytail were implanted with PT-4 acoustic transmitters (Sonotronics, Inc.). This tag is small (25 x 9 mm) and has a battery life of approximately 3 months. Adult razorback suckers captured from the river were implanted with CT-05-36-I acoustic transmitters, which are larger tags (63 x 15.6 mm) and have a battery life of approximately 36 months.

Before surgery, individual fish were immersed into a dark container with approximately 16-L of fresh water and tricaine methanesulfonate (MS-222; 125 mg L^{-1}) to anesthetize it. A successfully anesthetized fish was indicated by lack of operculation, weak muscular movements, and cessation of fin movements. Once these criteria were met, the fish was removed from the container, measured (TL in mm), weighed (nearest gram), and scanned for a 134.2-kHz PIT tag. The fish was then placed on a surgery cradle, ventral side up, and covered in a wet towel to eliminate desiccation. Anesthesia was maintained by gently pumping MS-222 solution with a small tube (4.77-mm) via the mouth across the gills for the remainder of the surgical procedure. A short (< 2 centimeters) mediolateral incision was made slightly anterior and dorsal to the left pelvic fin, and an acoustic transmitter sanitized in 70% ethanol was inserted into the abdominal cavity. Fishes absent of a PIT tag were implanted with a 134.2-kHz tag via the mediolateral incision. The incision was closed with two to three knots using a 4-0 absorbable braided, coated suture and an RB-1 (CV-23), 17 mm, ½ taper needle (AD Surgical, Sunnyvale, California). Post-surgery fishes received additional care to prevent infection (Martinsen and Horsberg 1995): the sutured wound was swabbed with Betadine, and a 10 mg/kg dosage of the antibiotic Baytril® (enrofloxacin) was injected into the dorsolateral musculature to mitigate infection.

October

On October 29, 2019, 10 razorback suckers and 9 bonytail were selected from a stocking cohort and surgically implanted with model PT-4 acoustic transmitters at the A10 lower culvert (objective 4) (table 1). Telemetry fishes selected from stocking cohorts are referred to as subadults throughout this report; however, sexual maturity was not assessed. Fishes were released into A10 lower immediately post-surgery. The mean TL of subadult razorback suckers was 471 mm (442–546 mm), and the mean TL of bonytail was 451 mm (420–472 mm).

Table 1.—Subadult razorback suckers and bonytail released in A10 lower, LCR, Arizona, October 29, 2019

Tag ID	Frequency	Interval (milliseconds)	Code	TL (mm)	Weight (grams)	PIT tag number
Razorback suckers						
200	73	990	3-3-6-8	442	957	3DD.003BFECD48
201	74	1,160	4-6-5-7	460	1,369	3DD.003BFECD4C
202	75	1,190	4-8-7-8	461	1,309	3DD.003BFECD2B
203	76	1,180	4-8-8-8	453	1,046	3DD.003BFECD3A
204	77	1,210	5-6-6-6	546	1,149	3DD.003BFECD37
205	78	1,200	5-6-6-7	471	1,087	3DD.003BFECD34
206	79	1,230	5-8-6-6	448	929	3DD.003BFECD3F
207	80	1,220	5-8-6-7	447	1,074	3DD.003BFECD4B
208	81	1,250	6-8-8-8	475	1,440	3DD.003BFECD44
209	82	1,240	7-8-8-8	506	1,453	3DD.003BFECD50
Bonytail						
211	69	890	3-5-8	472	1,349	3DD.003BFECD3C
212	70	940	5-7-8	435	874	3DD.003BFECD2E
213	71	950	5-8-6	453	1,010	3DD.003BFECD45
214	72	960	3-3-3-7	470	1,055	3DD.003BFECD2D
215	73	1,170	4-6-5-6	446	824	3DD.003BFECD22
216	74	980	3-3-7-4	461	950	3DD.003BFECD24
217	75	990	3-3-7-5	442	867	3DD.003BFECD4F
218	76	1,000	3-4-4-6	420	695	3DD.003BFECD47
219	77	1,010	3-4-4-7	458	778	3DD.003BFECD3E

January

On January 15–16, Marsh &Associates, LLC (M&A) personnel joined a Bureau of Reclamation team to electrofish in the main channel to procure for tag implantation razorback suckers that had naturalized to the study area. Suitable habitat was targeted, and more than 10 fish large enough for tag implantation were collected. On January 17, 2020, 10 of the captured razorback suckers were surgically implanted with CT-05-36-I acoustic transmitters at the A10 lower culvert (objective 3) (table 2). Fish were released into A10 lower immediately post-surgery. The mean TL of razorback suckers was 518 mm (480–576 mm).

Table 2.—Adult razorback suckers released in A10 lower, LCR, Arizona, January 17, 2020
(All were captured by electrofishing in the Colorado River main channel)

Tag ID	Frequency	Interval (milliseconds)	Code	TL (mm)	Weight (grams)	PIT tag number
170	73	1,050	3-5-4-8	511	1,460	3DD.003C07AC72
171	74	1,220	5-7-7-7	500	1,164	3DD.003BF31B74
172	75	1,250	6-7-6-7	576	1,927	3DD.003C072CD3
173	76	1,240	6-7-6-8	575	1,938	3DD.003C0245D4
174	77	870	3-4-6	480	1,212	3DD.003D4F7844
175	78	860	3-4-7	496	1,190	3DD.003D4F55FD
176	79	890	3-7-8	566	2,097	3DD.003BEA5BEE
177	80	880	3-8-4	490	1,388	3DD.003C07303B
178	81	910	4-6-7	488	1,340	3DD.003D4F727D
179	82	900	4-6-8	500	1,250	3DD.003C073815

On January 30, 2020, 10 subadult razorback suckers and 11 subadult bonytail were surgically implanted with model PT-4 acoustic transmitters at A10 lower culvert (objective 4) (table 3). Fishes were released into A10 lower immediately post-surgery. The mean TL of subadult razorback suckers was 395 mm (376–420 mm), and the mean TL of bonytail was 429 (397–475 mm).

Table 3.—Subadult razorback suckers and bonytail released in A10 lower, LCR, Arizona, January 30, 2020

Tag ID	Frequency	Interval (milliseconds)	Code	TL (mm)	Weight (grams)	PIT tag #
Razorback suckers						
230	73	970	3-3-3-8	420	701	3DD.003BCBF743
231	74	1,140	4-5-5-5	396	610	3DD.003BCBF75E
232	75	1,170	4-6-5-8	402	595	3DD.003BCBF735
233	76	1,160	4-6-6-6	384	555	3DD.003BCBF71E
234	77	1,190	5-5-5-6	376	544	3D9.1C2D6D131A
235	78	1,180	5-5-5-7	404	654	3DD.003BCBF720
236	79	1,210	5-6-6-8	398	639	3DD.003BCBF747
237	80	1,200	5-6-7-7	384	533	3DD.003BCBF777
238	81	1,230	5-8-6-8	404	569	3DD.003BCBF765
239	82	1,220	5-8-7-7	378	526	3D9.1C2D6BC713
Bonytail						
210	83	870	3-5-7	420	796	3DD.003BFECD49
220	78	1,020	3-4-7-8	417	733	3DD.003BFECCFC
221	79	1,030	3-4-8-8	437	803	3DD.003BFECD19
222	80	1,040	3-5-6-6	403	636	3DD.003BFECD11
223	81	1,050	3-5-6-7	426	611	3DD.003BFECD2F
224	82	1,060	3-6-4-5	456	894	3DD.003BFECD38
225	83	1,070	3-6-4-6	397	538	3DD.003BFECD0E
226	69	1,110	3-7-3-8	437	677	3DD.003BFECD27
227	70	1,100	3-7-4-7	440	830	3DD.003BFECD18
228	71	1,130	4-4-4-8	408	574	3DD.003BFECD0A
229	72	1,120	4-4-5-5	475	1,028	3DD.003BFECD43

Remote PIT Tag Sensing

Twenty PIT scanners were deployed during six monthly field sampling trips between October 28, 2019, and April 19, 2020 (objectives 1 and 2). Two additional sampling trips were conducted to maximize PIT scanning contacts during peak razorback sucker spawning in January and February. Each sampling trip was 5 days. Each backwater, A7 upper, A10 upper, A10 lower, C7 McIntyre Park, and C10 Ehler's (see figure 2) received at least two PIT scanners throughout the sampling trips.

Typically, between 8 and 10 units were placed in the main channel. These deployments targeted locations of swift-moving water over gravel, based on habitat preference for spawning razorback suckers (Minckley 1983; Tyus 1987). Throughout the study area, this habitat type has been scarce due to channelization and rip-rap levees on riverbanks; however, low water levels in SY 2019 led to the discovery of additional areas with the potentially preferred habitat (swift riverine habitat with gravel substrate) adjacent to the channelizing riprap in several locales. Upon the discovery of these locations, these areas became the focal points of PIT scanners deployed in the river.

In addition to standardized PIT scanner deployments, semipermanent custom units were placed in each of the culverts in A10 upper (figure 5). The unit in the lower culvert was a standard 4 x 2 foot (122 x 61 centimeter) antenna adapted to be used in the culvert (figure 5, left image). The unit placed in the upper culvert was a 3.2 x 1.6 foot (98 x 48 centimeter) rectangle made of 1-¼-inch schedule-80 polyvinyl chloride pipe (figure 5, right image). Both units were attached with brackets on each side of the circular culverts. The brackets were configured to secure the antenna in the culvert while allowing fishes to pass above or below the antenna; the water level in the culvert varied from low to full in response to periodic fluctuations in river stage. In both units, a 5-conductor cable connected the antennas to their respective data loggers and was passed through an additional hole drilled into the side of the culvert. Data loggers (mini loggers) and two or three 7.4-volt, 20 amp-hour Li-Ion batteries providing power to each of the units were secured inside watertight plastic housings partially buried within 8 m of their respective culverts. Both units were "single-wound" antennas.

Remote PIT Scanning Antenna Orientation Study

Due to years of low contact rates for PIT-tagged bonytail during this study, an experiment was designed and conducted in SY 2019 to determine if contact rates could be improved by changing PIT scanner orientation or using larger PIT tags; 32-mm, 134.2-kHz half duplex (HDX) PIT tags (Miller et al. 2020). Bonytail behaviorally inhabit a higher level in the water column than razorback suckers, which could reduce the contact rate for remote sensing equipment when deployed flat on the substrate (Henne et al. 2007).

Figure 5.—Culvert PIT scanner installation at the downstream culvert connecting A10 upper to A10 lower (left) and the upstream culvert connecting A10 upper to the main channel Colorado River (right), LCR, Arizona.

Results of the SY 2019 study showed that 32-mm HDX PIT tags were contacted at a greater rate than the typical 12-mm, 134.2-kHz FDX tags; however, results of the antenna orientation portion of the study were inconclusive. In SY 2020, the antenna orientation experiment was redesigned with more antenna deployments and with all fishes having the larger PIT tags.

To test if PIT scanner orientation would improve contact rates for bonytail, PIT scanners were placed in two orientations: bottom flat (lying flat on the substrate), which is the standard deployment orientation for contacting razorback suckers (control orientation), and bottom long (standing upright with longest edge contacting the substrate), which extends the contact field higher in the water column but reduces substrate surface coverage (experimental orientation).

On February 24, 2020, 400 bonytail implanted with 32-mm, 134.2-kHz HDX PIT tags were released in A10 upper. For two, 5-day sample periods (February 24 to 28 and March 9 to 13), eight PIT scanners were deployed in two locations within A10 upper. At each location, two were deployed bottom flat, and two were deployed bottom long by attaching a float to the top of the PIT scanner, causing the unit to stand upright in the water while maintaining direct contact with the substrate.

The two locations used for this study were selected for having a stretch of at least 80 m of uniform habitat along the bank and being sufficiently far away from the release location (A10 upper boat ramp) such that bonytail would be displaying typical swimming behavior rather than immediate post-release dispersal behavior. The two locations were defined as Location A and Location B (figure 6). The start of each location was determined to be the point along the bank that was closest to the release location. At each location, the first antenna was deployed 10 m into the start of the location, and each subsequent antenna was deployed every 15 m along the bank, for a total of four antennas at each location. Antenna orientation was alternated between bottom flat and bottom long within each location: the first and third antennas were one orientation, and the second and fourth antennas were the other orientation. Each antenna was deployed at approximately the same distance from the bank and at a depth of about 1 m.

For the first week of the study (February 24–28), the orientation for the first antenna in Location A was randomly determined by a coin flip, and the opposite orientation was used for the first antenna in Location B. Antennas were deployed on February 24 and left to scan for 4 days. However, upon retrieval on February 28, it was found that all bottom long antennas had fallen over to a bottom flat orientation due to waterlogging of the floats used to maintain bottom long orientation.

For the second week of the study (March 9–13), each antenna was checked and the data downloaded daily to ensure it was still in the proper orientation. The first deployment was on March 9, and all orientations were opposite those from the first week of the study. All antennas were left in that orientation for 2 days of scanning and then switched on March 11 and left to scan for two more days until retrieval on March 13. Only one of the 16 bottom long deployments fell to bottom flat during the second week of the study.

To assess the differences in contact rates between antenna orientations, the total number of unique bonytail contacts for each deployment was summarized based on orientation, and a generalized linear model assuming a Poisson distribution with a log link was used to statistically compare contact rates of the two orientations. The model included antenna orientation, location, and deployment date as predictor variables. Data from deployments of bottom long orientation that fell to bottom flat orientation were not included in the model.

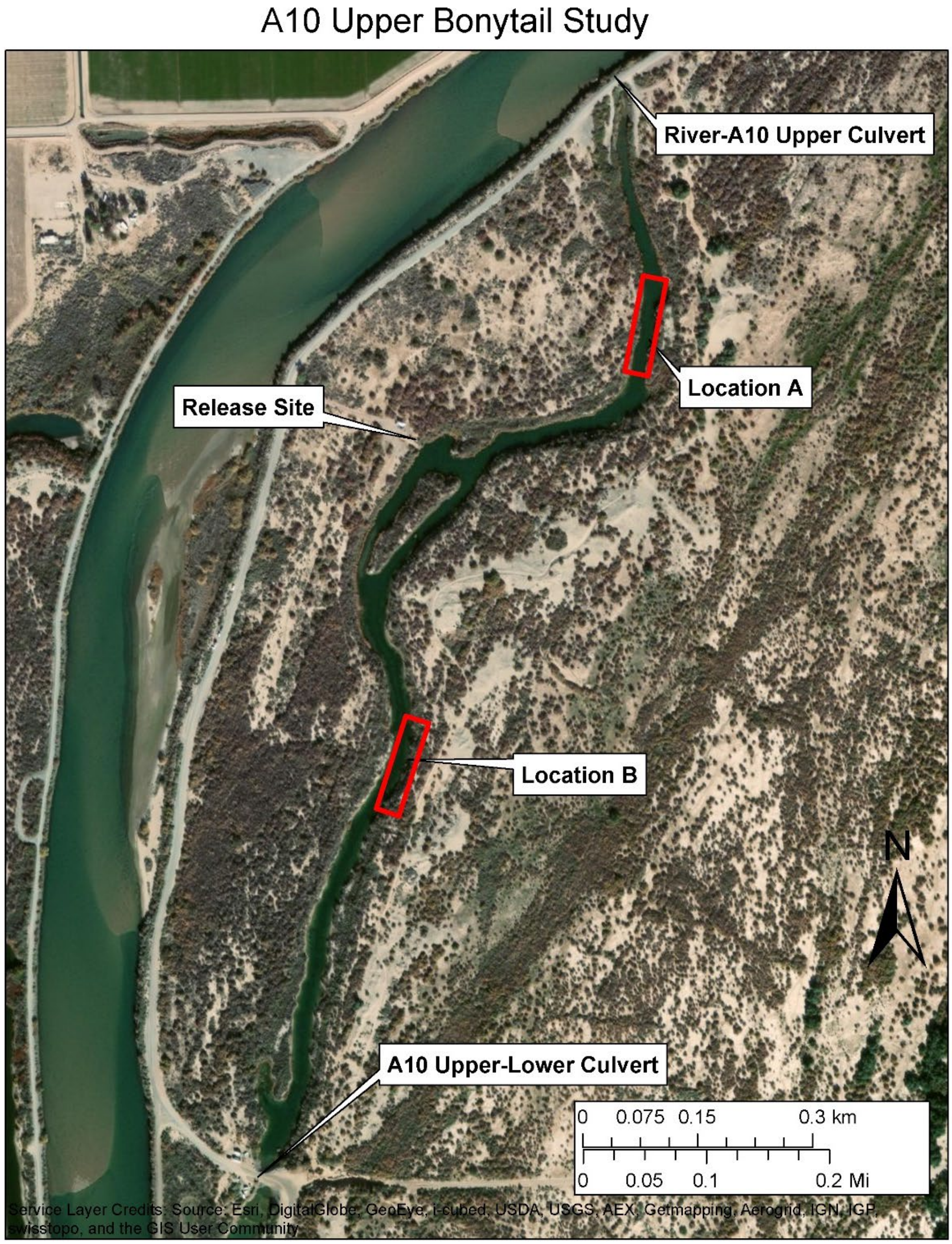

Figure 6.—Map of bonytail scanner orientation and survival study in A10 upper, LCR, Arizona and California.

Bonytail A10 Upper Survival Study

With years of low contact rates for bonytail suggesting that bonytail may die off quickly after stocking, a bonytail post-stocking survival study was designed to coincide with the scanner orientation study. The study was conducted in A10 upper, which is somewhat isolated compared to the other backwaters because it is only connected to other bodies of water via two culverts. Emigration out of A10 upper was monitored by PIT scanners in each culvert, allowing for emigration to be distinguished from mortality.

Bonytail released to evaluate remote PIT scanning antenna orientation also were used as subjects for the post-stocking survival study. The two culverts connecting the backwater to other bodies of water (the main channel at the upstream end and the lower half of the backwater at the downstream end) had PIT scanners as described above with a battery life in excess of 2 weeks. These units were used to monitor emigration from the study area. The antenna deployments used in the orientation study were also used for the bonytail survival study. There were eight PIT scanners deployed in A10 upper for the orientation study from February 24 to 28 and again from March 9 to 13. One to four additional antennas were deployed at a time to supplement the survival study, including one antenna left to scan between the February and March trips, and several antennas left to scan after the March trip until their batteries were fully discharged.

To assess bonytail post-stocking survival, daily survival rates were estimated using a Cormack-Jolly-Seber mark-recapture modeling approach. Each session was defined by each date. All scanning data in A10 upper were used to generate capture histories. Constant and time-dependent models were set up for both survival and capture probability. The lowest Akaike’s information criterion (AIC_c) score (Akaike 1974) was used to select the best model. If the top model weight was less than 0.9, model averaging was used for parameter estimates. The median c-hat goodness of fit test was used to assess overdispersion and adjust AIC_c values if necessary. All data were prepared via the program R (R Core Development Team 2018), models were set up with the package RMark (Laake 2013), and the program Mark (Cooch and White 2016) was used for goodness of fit testing and model averaging.

Population Estimates

Population estimates for razorback suckers and bonytail were based on remote PIT tag sensing data when paired year-to-year sample data included four or more recaptures (objective 5); the probability of systematic bias in the estimate can be ignored if there are four or more recaptures (Ricker 1975). Data for population estimates were based on the scanning period from October 1 to April 30 of each

SY, giving the fish 6 months between mark and capture periods to randomly assort.
The mark-recapture estimate for each species was based on the modified Peterson formula:

$$N^* = \frac{(M+1)(C+1)}{R+1} \qquad \text{(Ricker 1975)}$$

For each mark-recapture estimate, the number of individual PIT tags contacted in a 2-month scanning period encompassing the peak of razorback sucker spawning (January 1 through the end of February) of the previous SY was the mark (*M*), the number contacted in the current SY the capture (*C*), and the number in common between both years the recaptures (*R*). Any contacts with PIT tags released after May 31 of the marking year (May 31 of the previous SY) were removed from population estimates. Contacts with the second PIT tag in double-tagged fish were assessed for inclusion, but none fit the criteria. CIs were derived from Poisson approximation tables, using *R* as the entering variable when recaptures were 50 or less (Ricker 1975, Appendix II), or they were based on the normal distribution for 51 or more recaptures (Seber 1973).

For normal CIs, the Chapman estimate of large sample variance was used to calculate the standard error:

$$SE = \sqrt{\frac{(M+1)^2(C+1)(C-R)}{(R+2)(R+1)^2}} \qquad \text{(Ricker 1975)}$$

Post-Stocking Survival and Dispersal

A combination of QGIS (QGIS Development Team 2017) and R (R Core Development Team 2018) was used to calculate dispersal between SURs. First, polyline data from the National Hydrography Dataset Plus were used to represent the river network. Dispersal was calculated as the path along the river network instead of straight-line distance (i.e., Euclidean). The river network was spatially constrained to the extent of the study area, and dispersal distance calculations were performed in R. Dispersal distance (kilometers [km]) was calculated using point data (i.e., SUR locations) for all individuals. Dispersal was calculated between contacts only when an individual moved between SUR locations; therefore, a dispersal distance of zero was not possible. The “riverdistanceseq” function in the “riverdist” package (Tyers 2017) was used to calculate the network distance between sequential SUR contacts of individuals. Dispersal distance was only measured for fishes that left their release backwater.

If a tag was contacted multiple times via manual tracking in the same location, the fish was suspected dead, and the site was marked for tag retrieval via a scuba diver at the end of the field season. The date of first contact at the spot of retrieval was used as the day the fish was determined dead.

Scanning Probability Modeling

Assessing post-stocking survival using mark-recapture estimation has been problematic due to low post-stocking survival (less than 5%). However, PIT tag scanning has increased the probability of encounter to as high as 90% when effort is spatially and temporally adequate (Miller et al. 2020). Spatial and temporal coverage for this project is still being evaluated; however, insights into factors affecting post-stocking survival may be gained by analyzing the available data in a generalized additive model (GAM). GAMs make no assumptions about the distribution of data, allowing for assessment of nonparametric relationships. The only assumptions of GAMs are that the functions of each predictor are additive (no interactive effects) and that the components of each smoothed predictor function are indeed smooth. These models are ideal for nonparametric (nonlinear) relationships; therefore, this report includes preliminary results from this analysis.

A GAM was developed with monthly scanning probability as the dependent variable. Monthly scanning probability was defined as the probability a released fish was scanned in each month. Only months when M&A scanning trips occurred were included in the model, October through March, inclusive, covering the period from October 2016 through March 2020. Every fish with a release record was marked as scanned (1) or not scanned (0) during every scanning month after release, excluding scanning months during the release SY. The probability of being scanned each month was modeled as a GAM with a logit link in program R (R Core Development Team 2018) using the package mgcv (Wood 2011). Predictor covariates included TL, release location, months at large (MAL), the number of months since release, and scanning month. Scanning month as a factor was included to account for differences in scanning effort and differences in availability during the spawning season. MAL was included to account for long-term survival characteristics that are independent of post-stocking survival. The predictor variables TL and MAL were smoothed using the default parameters in the mgcv package.

Adult Razorback Sucker Survival

Development of a mark-recapture model to estimate adult survival is ongoing (objective 6), with preliminary results reported here. The robust model type was selected to estimate adult survival based on monthly PIT scanning data. Robust models combine closed, repeated sampling occasions during which no mortality or migration occurs (secondary sessions), with open periods between secondary sessions with mortality and temporary migration (primary sessions, Kendall et al.

1997). Routine scanning trips conducted from October through March each study year were treated as closed sampling sessions and the time between study years (April through August) as open periods.

The robust model assumes demographic closure during a study year, no migration, and no mortality between secondary sampling occasions. Post-release apparent mortality is highest within the first 6 months after release (Karam et al. 2008; Schooley et al. 2008). To avoid the high mortality of post-stocking affecting estimates of established adult survival, the models only included data for individuals scanned at least two SYs after release (i.e., an individual released in SY 2018 would not be counted until SY 2020).

Survival (S) was modeled as both constant and time dependent (based on SY). Capture (p) and recapture (c) rates were set equal for any given sample occasion (hereon referred to as contact rates) because the likelihood of either is equivalent when both are represented by PIT scanning contacts. PIT scanning effort varied from month to month, and contact rates were higher during peak spawning months (January through February) compared to other sampling months; therefore, contact rates in all models were independent for every sampling occasion. Different migration parameterizations of γ'' (probability of temporary emigration from the observable study area) and γ' (probability of remaining away from the observable study area) were modeled to represent three potential temporary emigration patterns: no temporary emigration (γ'' and γ' fixed at 0), random emigration (γ'' equals γ' for each between session period), and Markovian emigration (γ'' and γ' independent and time varying); see Kendall et al. (1997) for further explanation. In all models with time varying migration and survival, the last parameter values of both migration rates (γ'' and γ') were constrained to equal values from the penultimate period to eliminate confounding of parameters (Kendall et al. 1997).

Models were ranked based on AIC_c scores, and the reported parameter values were based on the highest ranked model. If the top model weight was less than 0.9, model averaging was used for parameter estimates. All data were prepared via the program R (R Core Development Team 2018), models were set up with the package RMark (Laake 2013), and the program Mark (Cooch and White 2016) was used for model averaging.

Habitat Use

The relative use of backwater and riverine habitats for all telemetry fishes was summarized to assess preferred habitats (objectives 3 and 4). The contact record for each telemetry fish was assessed, and each fish was assigned a habitat use as described in table 4. Some fishes were classified into categories that were excluded from habitat use evaluation. Individuals that were contacted only in their release backwater provide limited insight into relative habitat use because they may have died or were lost shortly after release and did not establish long enough to evaluate their behavior. The same can be said for individuals that were contacted briefly in the main channel before being lost, since they disappeared with limited data to evaluate habitat use. The excluded categories are also in table 4.

Table 4.—Habitat use characterization criteria for telemetry fish

Habitat use category	Criteria
Backwaters	Mainly contacted in backwaters, with river contacts only occurring when moving between backwaters
Backwaters with periodic river	Mainly contacted in backwaters, but made occasional trips into the river, particularly at the C7 gravel bar
River and backwaters	Used widespread areas up and down the river and in backwaters
River	Mainly used river habitat, with minimal use of backwaters
Excluded categories	
Never contacted	Never contacted via telemetry
Only contacted in release backwater	Never contacted outside of their release backwater
Disappeared in main channel	Briefly contacted in the main channel after leaving a backwater and were never contacted again

RESULTS

Releases

Totals of 45,256 razorback suckers and 31,778 bonytail were released with 134-kHz tags into the 5 focal backwaters, as well as some river locations, between January 2007 and March 3, 2020 (tables 5 and 6), based on records in the Lower Colorado River Native Fish Database. In SY 2020 (from October 1, 2019, through April 30, 2020), 10,810 razorback suckers and 5,044 bonytail were released. Released fishes were reared at the Arizona Game and Fish Department Bubbling Ponds State Fish Hatchery, USFWS Imperial Ponds Conservation Area (IPCA), USFWS Southwestern Native Aquatic Resources and Recovery Center, Dexter, New Mexico (Center) (previously named Dexter National Fish Hatchery), Nevada Department of Wildlife Lake Mead Fish Hatchery, and USFWS Achii Hanyo Native Fish Rearing Facility, a satellite of Willow Beach National Fish Hatchery, Arizona. Release sizes ranged from 305 to 668 mm TL for razorback suckers and from 240 to 475 mm TL for bonytail during SY 2020.

Table 5.—Razorback sucker releases (January 2007 through April 2020) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts, LCR, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of the most recent remote sensing contact and release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2020 contacts	TL mean (range)	Days at large mean (range)
	Before September 2014		1,959	46	1	364 (300 – 624)	1,698 (314 – 4,521)
11/6/2014	A10 lower	IPCA	1	0	0	635 (635 – 635)	0 (–)
12/5/2014	A10 lower	IPCA	16	10	0	502 (275 – 585)	243 (11 – 1,519)
12/5/2014	A10 lower	IPCA	3	1	0	578 (520 – 615)	11 (11 – 11)
12/5/2014	A10 upper/lower	IPCA	3	0	0	577 (560 – 610)	0 (–)
12/5/2014	A10 upper/lower	IPCA	2	1	0	615 (590 – 640)	161 (161 – 161)
12/5/2014	A10 upper/lower	IPCA	2	0	0	608 (590 – 625)	0 (–)
12/5/2014	A10 lower	IPCA	3	1	0	590 (565 – 625)	76 (76 – 76)
12/5/2014	A10 lower	IPCA	1	0	0	540 (540 – 540)	0 (–)
4/2/2015	A10 lower	Bubbling Ponds Fish Hatchery	1,019	190	7	344 (305 – 440)	113 (0 – 1,820)
4/2/2015	A10 upper	Bubbling Ponds Fish Hatchery	778	174	47	347 (305 – 420)	937 (0 – 1,823)
12/8/2015	A7 upper	Achii Hanyo	1,212	31	0	336 (305 – 460)	16 (0 – 94)
12/9/2015	Oxbow Campground Recreational Area	Achii Hanyo	1,160	160	0	346 (305 – 455)	3 (0 – 76)
2/18/2016	A10 lower	Bubbling Ponds Fish Hatchery	518	12	0	338 (305 – 470)	272 (7 – 1,078)
2/18/2016	Oxbow Campground Recreational Area	Bubbling Ponds Fish Hatchery	516	14	0	336 (305 – 445)	93 (5 – 1,101)
4/28/2016	A10 upper	Bubbling Ponds Fish Hatchery	1,106	24	5	351 (305 – 450)	523 (46 – 1,425)
4/28/2016	Oxbow Campground Recreational Area	Bubbling Ponds Fish Hatchery	981	10	0	351 (305 – 445)	356 (47 – 1,057)
10/27/2016	A10 lower	Bubbling Ponds Fish Hatchery	629	48	0	358 (305 – 440)	16 (0 – 265)
10/27/2016	A10 upper	Bubbling Ponds Fish Hatchery	628	26	0	356 (305 – 455)	131 (12 – 828)
10/27/2016	A7 upper	Bubbling Ponds Fish Hatchery	630	17	0	353 (305 – 450)	20 (0 – 84)

Table 5.—Razorback sucker releases (January 2007 through April 2020) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts, LCR, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of the most recent remote sensing contact and release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2020 contacts	TL mean (range)	Days at large mean (range)
10/27/2016	C7 McIntyre Park	Bubbling Ponds Fish Hatchery	625	45	0	359 (305 – 465)	68 (0 – 844)
10/27/2016	C10 Ehler's	Bubbling Ponds Fish Hatchery	633	63	0	360 (305 – 465)	48 (0 – 855)
11/17/2016	A10 upper	Bubbling Ponds Fish Hatchery	600	18	1	356 (305 – 465)	134 (18 – 1,214)
11/17/2016	A7 upper	Bubbling Ponds Fish Hatchery	574	3	0	354 (305 – 485)	35 (19 – 63)
11/17/2016	C7 McIntyre Park	Bubbling Ponds Fish Hatchery	467	13	0	358 (305 – 480)	65 (18 – 446)
11/17/2016	C10 Ehler's	Bubbling Ponds Fish Hatchery	598	10	0	354 (305 – 485)	195 (18 – 829)
12/14/2016	A10 upper	Lake Mead Fish Hatchery	10	3	2	456 (425 – 495)	822 (72 – 1,198)
1/25/2017	A10 lower	Lake Mead Fish Hatchery	215	0	0	447 (334 – 540)	0 (–)
1/25/2017	A7 upper	Lake Mead Fish Hatchery	322	4	1	455 (362 – 550)	298 (21 – 1,128)
5/4/2017	A10 lower	Lake Mead Fish Hatchery	202	33	3	419 (320 – 539)	371 (20 – 1,041)
5/4/2017	C7 McIntyre Park	Lake Mead Fish Hatchery	182	40	2	418 (312 – 509)	240 (21 – 1,029)
5/4/2017	Mayflower at Hidden Beaches Resort	Lake Mead Fish Hatchery	200	5	0	422 (318 – 530)	356 (131 – 664)
11/16/2017	A10 upper	Bubbling Ponds Fish Hatchery	665	65	10	357 (305 – 465)	254 (0 – 863)
11/16/2017	C7 McIntyre Park	Bubbling Ponds Fish Hatchery	594	42	0	353 (305 – 455)	117 (0 – 490)
11/16/2017	C10 Ehler's	Bubbling Ponds Fish Hatchery	580	151	1	355 (305 – 455)	12 (0 – 820)
1/18/2018	A10 lower	Lake Mead Fish Hatchery	15	6	0	459 (420 – 504)	14 (0 – 43)
1/19/2018	A10 lower	Bubbling Ponds Fish Hatchery	464	279	18	411 (335 – 485)	124 (4 – 797)

Table 5.—Razorback sucker releases (January 2007 through April 2020) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts, LCR, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of the most recent remote sensing contact and release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2020 contacts	TL mean (range)	Days at large mean (range)
1/19/2018	A10 upper	Bubbling Ponds Fish Hatchery	459	323	41	413 (335 – 480)	193 (5 – 797)
1/19/2018	A7 upper	Bubbling Ponds Fish Hatchery	461	73	5	409 (325 – 515)	198 (18 – 756)
2/7/2018	C10 Ehler's	Lake Mead Fish Hatchery	16	0	0	448 (401 – 481)	0 (–)
2/15/2018	A10 lower	Bubbling Ponds Fish Hatchery	506	114	4	360 (305 – 460)	71 (0 – 770)
2/15/2018	A10 upper	Bubbling Ponds Fish Hatchery	510	108	8	360 (305 – 480)	101 (5 – 770)
2/15/2018	A7 upper	Bubbling Ponds Fish Hatchery	501	34	5	363 (305 – 470)	282 (6 – 758)
2/15/2018	Colorado River downstream from Ehrenberg Bridge	Bubbling Ponds Fish Hatchery	510	18	1	364 (305 – 465)	175 (4 – 714)
2/16/2018	C7 McIntyre Park	Bubbling Ponds Fish Hatchery	384	27	3	358 (305 – 460)	151 (2 – 753)
2/16/2018	C10 Ehler's	Bubbling Ponds Fish Hatchery	300	8	0	362 (305 – 470)	152 (11 – 371)
11/8/2018	A10 lower	Bubbling Ponds Fish Hatchery	393	163	18	388 (305 – 480)	128 (0 – 507)
11/8/2018	A10 upper	Bubbling Ponds Fish Hatchery	391	152	40	387 (305 – 470)	204 (0 – 508)
11/8/2018	A7 upper	Bubbling Ponds Fish Hatchery	394	68	8	389 (305 – 495)	118 (0 – 503)
11/9/2018	C7 McIntyre Park	Bubbling Ponds Fish Hatchery	394	83	10	388 (310 – 497)	132 (33 – 489)
11/9/2018	C10 Ehler's	Bubbling Ponds Fish Hatchery	371	47	4	392 (311 – 472)	130 (33 – 459)
11/29/2018	Colorado River downstream from Ehrenberg Bridge	Bubbling Ponds Fish Hatchery	599	20	5	373 (305 – 478)	157 (15 – 471)
1/17/2019	Colorado River downstream from Ehrenberg Bridge	Bubbling Ponds Fish Hatchery	312	8	2	387 (305 – 484)	135 (14 – 404)

Table 5.—Razorback sucker releases (January 2007 through April 2020) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts, LCR, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of the most recent remote sensing contact and release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2020 contacts	TL mean (range)	Days at large mean (range)
1/31/2019	A10 lower	Bubbling Ponds Fish Hatchery	442	202	19	376 (305 – 486)	48 (0 – 421)
1/31/2019	A10 lower	Lake Mead Fish Hatchery	5	2	0	512 (495 – 530)	1 (0 – 1)
1/31/2019	A10 upper	Bubbling Ponds Fish Hatchery	440	219	21	371 (305 – 473)	51 (0 – 420)
1/31/2019	A10 upper	Lake Mead Fish Hatchery	10	10	1	505 (475 – 535)	71 (1 – 417)
1/31/2019	A7 upper	Bubbling Ponds Fish Hatchery	440	57	8	376 (305 – 479)	64 (0 – 417)
2/1/2019	C7 McIntyre Park	Bubbling Ponds Fish Hatchery	440	53	17	378 (305 – 479)	139 (17 – 417)
2/1/2019	C10 Ehler's	Bubbling Ponds Fish Hatchery	426	42	5	374 (305 – 458)	67 (17 – 416)
2/14/2019	A10 lower	Bubbling Ponds Fish Hatchery	476	95	16	359 (305 – 461)	72 (4 – 406)
2/14/2019	A7 upper	Bubbling Ponds Fish Hatchery	400	15	5	360 (305 – 460)	147 (4 – 395)
2/14/2019	C7 McIntyre Park	Bubbling Ponds Fish Hatchery	404	42	17	364 (305 – 468)	157 (4 – 397)
2/14/2019	C10 Ehler's	Bubbling Ponds Fish Hatchery	404	23	4	366 (305 – 484)	73 (4 – 391)
2/21/2019	A10 lower	Lake Mead Fish Hatchery	14	6	1	490 (452 – 526)	73 (0 – 399)
2/28/2019	A10 lower	Bubbling Ponds Fish Hatchery	274	13	10	349 (305 – 427)	281 (0 – 380)
2/28/2019	A10 upper	Bubbling Ponds Fish Hatchery	550	142	10	354 (305 – 460)	28 (0 – 394)
2/28/2019	A7 upper	Bubbling Ponds Fish Hatchery	299	7	5	355 (305 – 464)	255 (0 – 377)
2/28/2019	Ehrenberg Bridge boat ramp	Bubbling Ponds Fish Hatchery	550	17	16	350 (305 – 475)	340 (20 – 386)
3/21/2019	A10 upper	Bubbling Ponds Fish Hatchery	450	208	179	354 (305 – 461)	311 (0 – 375)

Table 5.—Razorback sucker releases (January 2007 through April 2020) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts, LCR, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of the most recent remote sensing contact and release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2020 contacts	TL mean (range)	Days at large mean (range)
3/21/2019	C7 McIntyre Park	Bubbling Ponds Fish Hatchery	475	101	59	354 (305 – 460)	201 (0 – 371)
3/21/2019	C10 Ehler's	Bubbling Ponds Fish Hatchery	480	53	41	356 (305 – 439)	250 (0 – 368)
3/21/2019	Ehrenberg Bridge boat ramp	Bubbling Ponds Fish Hatchery	476	21	20	354 (305 – 428)	327 (1 – 365)
4/4/2019	A10 lower	Bubbling Ponds Fish Hatchery	489	52	49	359 (305 – 475)	323 (131 – 360)
4/4/2019	A7 upper	Bubbling Ponds Fish Hatchery	564	30	30	361 (305 – 454)	324 (286 – 353)
4/4/2019	C7 McIntyre Park	Bubbling Ponds Fish Hatchery	398	45	45	354 (305 – 456)	326 (250 – 361)
4/4/2019	C10 Ehler's	Bubbling Ponds Fish Hatchery	394	27	26	358 (305 – 475)	314 (105 – 351)
4/5/2019	A10 upper	Bubbling Ponds Fish Hatchery	249	60	60	358 (305 – 457)	339 (208 – 359)
4/5/2019	Ehrenberg Bridge boat ramp	Bubbling Ponds Fish Hatchery	283	7	7	356 (305 – 462)	324 (300 – 348)
10/29/2019	A10 lower	Lake Mead larvae	13	6	6	460 (442 – 506)	100 (0 – 135)
10/31/2019	A10 lower	Bubbling Ponds Fish Hatchery	430	184	184	409 (306 – 480)	90 (0 – 147)
10/31/2019	A10 upper	Bubbling Ponds Fish Hatchery	436	271	271	411 (310 – 501)	119 (0 – 151)
11/1/2019	A7 upper	Bubbling Ponds Fish Hatchery	627	103	103	403 (311 – 485)	100 (38 – 143)
11/21/2019	C7 McIntyre Park	Bubbling Ponds Fish Hatchery	500	162	162	410 (305 – 505)	89 (18 – 126)
11/21/2019	C10 Ehler's	Bubbling Ponds Fish Hatchery	499	143	143	416 (305 – 495)	61 (19 – 123)
11/21/2019	Ehrenberg Bridge boat ramp	Bubbling Ponds Fish Hatchery	540	22	22	414 (305 – 498)	75 (19 – 126)
1/15/2020	A10 upper	Bubbling Ponds Fish Hatchery	585	197	197	381 (305 – 495)	52 (2 – 73)
1/16/2020	A7 upper	Bubbling Ponds Fish Hatchery	587	48	48	378 (305 – 472)	28 (6 – 60)

Table 5.—Razorback sucker releases (January 2007 through April 2020) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts, LCR, Arizona and California

(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of the most recent remote sensing contact and release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2020 contacts	TL mean (range)	Days at large mean (range)
1/17/2020	A10 lower	Bubbling Ponds Fish Hatchery	584	133	133	377 (305 – 476)	43 (6 – 72)
1/30/2020	A10 lower	Bubbling Ponds Fish Hatchery	533	173	173	370 (305 – 458)	14 (0 – 56)
1/30/2020	A10 lower	Lake Mead Fish Hatchery	15	1	1	408 (367 – 668)	27 (27 – 27)
1/30/2020	A10 upper	Bubbling Ponds Fish Hatchery	537	216	216	369 (305 – 460)	25 (0 – 59)
1/30/2020	A7 upper	Bubbling Ponds Fish Hatchery	536	9	9	364 (305 – 474)	34 (13 – 49)
1/31/2020	C7 McIntyre Park	Bubbling Ponds Fish Hatchery	528	47	47	368 (305 – 477)	32 (7 – 55)
1/31/2020	C10 Ehler's	Bubbling Ponds Fish Hatchery	517	11	11	364 (305 – 489)	27 (11 – 40)
2/13/2020	A7 upper	Bubbling Ponds Fish Hatchery	651	25	25	373 (305 – 482)	21 (11 – 41)
2/13/2020	C7 McIntyre Park	Bubbling Ponds Fish Hatchery	647	101	101	374 (305 – 467)	21 (0 – 41)
2/13/2020	C10 Ehler's	Bubbling Ponds Fish Hatchery	650	10	10	372 (305 – 476)	20 (12 – 33)
2/14/2020	A10 lower	Bubbling Ponds Fish Hatchery	646	146	146	375 (305 – 475)	18 (1 – 45)
2/14/2020	A10 upper	Bubbling Ponds Fish Hatchery	749	263	263	369 (305 – 457)	20 (0 – 41)
		Totals	45,256	6,611	3,194		

Table 6.—Bonytail releases (January 2007 through April 2020) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts LCR, Arizona and California.
(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2020 contacts	TL mean (range)	Days at large mean (range)
	Before September 2014		150	0	0	320 (275 – 405)	0 (–)
12/10/2014	A10 lower	Center	1,996	113	0	346 (305 – 425)	30 (6 – 278)
9/23/2015	A10 backwater	Center	2,865	47	0	324 (305 – 429)	50 (20 – 548)
10/26/2016	A10 upper	Center	600	32	0	323 (305 – 392)	18 (0 – 44)
10/26/2016	A7 upper	Center	600	13	0	326 (240 – 401)	25 (12 – 149)
10/26/2016	C7 McIntyre Park	Center	600	19	0	325 (223 – 385)	13 (0 – 44)
11/16/2016	A10 upper	Center	800	3	0	326 (305 – 395)	22 (19 – 23)
11/16/2016	A7 upper	Center	456	0	0	324 (305 – 397)	0 (–)
11/16/2016	C7 McIntyre Park	Center	700	3	0	326 (305 – 387)	21 (19 – 23)
11/16/2016	C10 Ehler's	Center	700	1	0	326 (305 – 535)	20 (20 – 20)
12/14/2016	A10 upper	Lake Mead Fish Hatchery	14	0	0	415 (405 – 428)	0 (–)
1/25/2017	A10 lower	Lake Mead Fish Hatchery	5	0	0	402 (385 – 416)	0 (–)
1/25/2017	A7 upper	Lake Mead Fish Hatchery	15	0	0	401 (366 – 435)	0 (–)
3/20/2017	C7 McIntyre Park	Lake Mead Fish Hatchery	1,445	206	0	349 (305 – 444)	3 (0 – 91)
4/25/2017	A7 upper	Center	750	1	0	312 (305 – 431)	31 (31 – 31)
10/11/2017	A10 upper	Center	404	27	0	339 (305 – 419)	80 (34 – 130)
10/11/2017	A7 upper	Center	500	17	0	336 (305 – 461)	47 (35 – 123)
10/11/2017	C7 McIntyre Park	Center	500	24	0	333 (305 – 439)	75 (34 – 124)
11/16/2017	C7, upper culvert	Lake Mead Fish Hatchery	15	0	0	447 (412 – 476)	0 (–)
12/5/2017	A10 lower	Center	600	48	0	343 (305 – 456)	67 (42 – 82)
12/5/2017	A10 upper	Center	600	85	0	343 (305 – 436)	35 (8 – 69)
12/5/2017	A7 upper	Center	600	6	0	344 (305 – 447)	45 (6 – 168)
12/5/2017	C10 Ehler's	Achii Hanyo	413	10	0	332 (305 – 440)	20 (6 – 52)
1/24/2018	A10 upper	Lake Mead Fish Hatchery	400	134	0	362 (305 – 466)	2 (0 – 19)
1/24/2018	C7 McIntyre Park	Lake Mead Fish Hatchery	300	78	0	361 (305 – 473)	4 (0 – 34)
1/24/2018	C10 Ehler's	Lake Mead Fish Hatchery	300	27	0	360 (305 – 458)	4 (1 – 36)

Table 6.—Bonytail releases (January 2007 through April 2020) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts LCR, Arizona and California.
(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2020 contacts	TL mean (range)	Days at large mean (range)
2/7/2018	A10 lower	Lake Mead Fish Hatchery	500	77	0	379 (305 – 475)	6 (0 – 104)
2/7/2018	A7 upper	Lake Mead Fish Hatchery	500	3	0	376 (305 – 510)	26 (12 – 43)
2/7/2018	C10 Ehler's	Lake Mead Fish Hatchery	350	1	0	359 (305 – 465)	23 (23 – 23)
4/4/2018	A10 upper	Lake Mead Fish Hatchery	390	11	0	355 (305 – 455)	56 (48 – 128)
4/4/2018	C7 McIntyre Park	Lake Mead Fish Hatchery	407	3	0	363 (305 – 480)	49 (48 – 50)
5/3/2018	A7 upper	Lake Mead Fish Hatchery	1,258	69	0	362 (305 – 480)	41 (19 – 127)
11/19/2018	A10 lower	Center	520	4	0	320 (305 – 396)	73 (22 – 123)
11/19/2018	A10 upper	Center	537	1	0	323 (305 – 395)	23 (23 – 23)
11/19/2018	A7 upper	Center	519	1	0	322 (305 – 396)	26 (26 – 26)
12/6/2018	C7 McIntyre Park	Achii Hanyo	430	2	0	348 (305 – 451)	8 (7 – 8)
12/6/2018	C10 Ehler's	Achii Hanyo	436	1	0	338 (305 – 426)	43 (43 – 43)
12/12/2018	A7 lower	Lake Mead Fish Hatchery	17	1	0	416 (358 – 482)	49 (49 – 49)
1/28/2019	A10 upper	Lake Mead Fish Hatchery	664	316	0	362 (318 – 448)	5 (0 – 31)
1/31/2019	A10 lower	Lake Mead Fish Hatchery	14	8	0	425 (375 – 500)	3 (0 – 20)
1/31/2019	A10 upper	Lake Mead Fish Hatchery	2	2	0	343 (315 – 370)	0 (0 – 0)
2/21/2019	A10 lower	Lake Mead Fish Hatchery	15	7	0	439 (384 – 493)	2 (0 – 7)
3/20/2019	A7 upper	Center	665	2	0	331 (305 – 430)	2 (1 – 2)
3/20/2019	Ehrenberg Bridge boat ramp	Center	600	1	0	316 (305 – 435)	2 (2 – 2)
3/25/2019	C7 McIntyre Park	Lake Mead Fish Hatchery	400	0	0	344 (305 – 410)	0 (–)
3/25/2019	C10 Ehler's	Lake Mead Fish Hatchery	400	0	0	337 (305 – 410)	0 (–)
3/25/2019	Ehrenberg Bridge boat ramp	Lake Mead Fish Hatchery	400	0	0	324 (305 – 410)	0 (–)

Table 6.—Bonytail releases (January 2007 through April 2020) downstream from Palo Verde Dam and their subsequent remote PIT sensing contacts LCR, Arizona and California.
(TL was recorded in mm, and days at large was calculated for each PIT tag as the difference between the date of most recent remote sensing contact and release date.)

Release date	Release location	Rearing site	Releases	Contacts	SY 2020 contacts	TL mean (range)	Days at large mean (range)
3/27/2019	A10 lower	Lake Mead Fish Hatchery	400	0	0	337 (305 – 440)	0 (–)
3/27/2019	A10 upper	Lake Mead Fish Hatchery	400	0	0	320 (305 – 420)	0 (–)
3/27/2019	A7 upper	Lake Mead Fish Hatchery	400	1	0	340 (305 – 422)	176 (176 – 176)
4/8/2019	Ehrenberg Bridge boat ramp	Lake Mead Fish Hatchery	179	0	0	333 (305 – 427)	0 (–)
4/8/2019	Imperial National Wildlife Refuge, main channel	Lake Mead Fish Hatchery	3	0	0	348 (315 – 385)	0 (–)
10/8/2019	A10 lower	Center	500	2	2	318 (305 – 357)	88 (35 – 23)
10/8/2019	A10 upper backwater ramp	Center	500	7	7	316 (305 – 361)	48 (21 – 42)
10/8/2019	A7 upper	Center	513	5	5	318 (305 – 370)	22 (20 – 23)
10/29/2019	A10 upper	Lake Mead larvae	15	3	3	435 (380 – 472)	14 (0 – 42)
1/15/2020	C7 McIntyre Park	Center	600	89	89	332 (305 – 425)	1 (0 – 14)
1/15/2020	C10 Ehler's	Center	600	5	5	331 (305 – 425)	26 (2 – 43)
1/15/2020	Ehrenberg Bridge boat ramp	Center	600	4	4	333 (305 – 423)	18 (1 – 29)
1/30/2020	A10 lower	Lake Mead Fish Hatchery	15	1	1	426 (393 – 475)	1 (1 – 1)
2/24/2020	A10 upper	Lake Mead Fish Hatchery	400	215	215	351 (305 – 434)	3 (0 – 23)
3/3/2020	A10 lower	Lake Mead Fish Hatchery	699	9	9	341 (242 – 445)	5 (1 – 9)
3/3/2020	A7 upper	Lake Mead Fish Hatchery	602	7	7	334 (240 – 454)	9 (8 – 10)
		Totals	31,778	1,752	347		

Remote PIT Tag Sensing

Throughout SY 2020, M&A biologists took eight trips to the study area, each lasting 5 days and 4 nights. During these trips, 253 PIT scanner deployments were made, totaling 17,623.2 hours of scan time (figure 7). Of these deployments, 158 were in the 5 focal backwaters for 10,926.7 scan hours. The remaining 95 were in the main channel of the Colorado River for 6,696.5 scan hours.

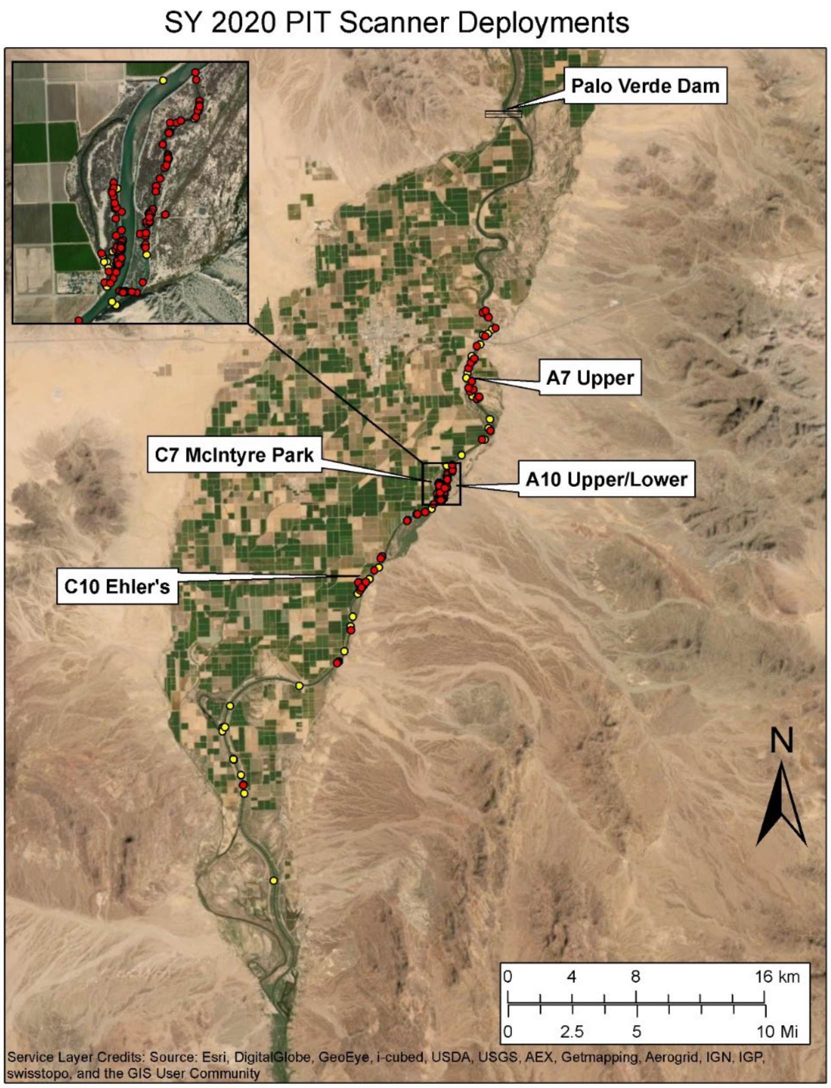

Figure 7.—Remote PIT scanner deployment locations for SY 2020, LCR, Arizona and California.
A red dot represents a location where at least one PIT contact was recorded. A yellow dot represents a location where no PIT tags were contacted.

Razorback Sucker Spawning Aggregations

A native fish aggregation site (figure 8) was identified during SY 2019; a gravel bar in the main channel Colorado River near the entrance to C7 McIntyre Park along the California shoreline (hereafter referred to as C7 gravel bar). A total of 989 unique PIT tags with records in the Lower Colorado River Native Fish Database were contacted in the main channel during SY 2020, and 919 (92.9%) of those were contacted at the C7 gravel bar (table 7). The 919 fish consisted of 915 razorback suckers and 4 bonytail. All four bonytail were released in fiscal year 2020, with three released at C7 McIntyre Park and one released at A10 upper.

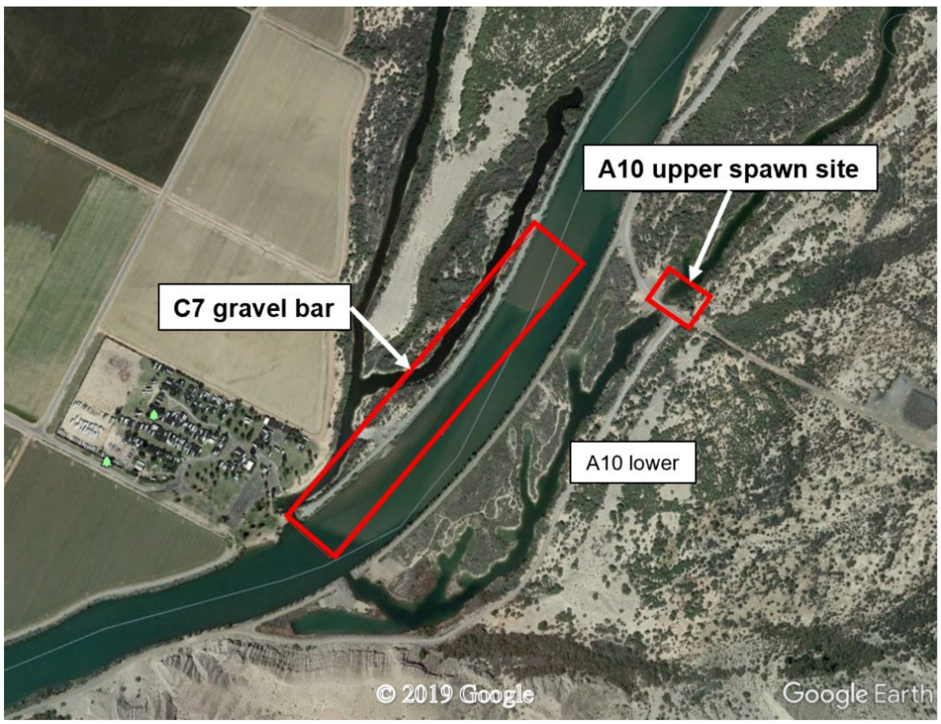

Figure 8.—Satellite imagery of two razorback sucker spawning aggregation sites, LCR, Arizona and California.

The majority of razorback suckers contacted at the C7 gravel bar, 626 of 915 (68.4%), were released in the most proximate backwaters (C7 McIntyre Park, A10 lower, and A10 upper). Four razorback suckers contacted at the C7 gravel bar were captured via electrofishing in the same location in January 2019 and January 2020, and one additional razorback sucker was captured and tagged at A7 upper in November 2012. A greater percentage of razorback suckers contacted at the C7 gravel bar was released in a previous SY, 402 of 910 (44.2%, excluding the 5 fish tagged at capture), compared to the percentage for total contacts in the SY (923 of 3,194; 28.9%). Out of the 402 contacted at the C7 gravel bar and released in a previous SY, 301 (74.9%) were not contacted at any other location in SY 2020.

Table 7.—Remote PIT scanning data from the C7 gravel bar, LCR, Arizona and California

Release location	Number of fish contacted	Mean days at large	Number of fish released in a previous SY
C7 McIntyre Park	316	187	126 (31.3%)
A10 lower	232	210	78 (19.4%)
A7 upper	129	259	55 (13.7%)
C10 Ehler's	100	222	49 (12.2%)
A10 upper	82	363	49 (12.2%)
Ehrenberg Bridge boat ramp	47	294	37 (9.2%)
Colorado River downstream from Ehrenberg Bridge	8	473	8 (2.0%)
Unknown (tagged at capture)	5	Unknown	Unknown
Totals	**919[1]**		**402**

[1] Four of the 919 fish contacted at the C7 gravel bar were bonytail.

There is one other known spawning aggregation (see figure 8) in the study area, located at the southernmost portion of A10 upper, just above the A10 upper-lower culvert (hereafter referred to as the A10 upper spawn site). A total of 1,566 unique razorback suckers were contacted at the A10 upper spawn site in SY 2020, 464 of which were released in a previous SY (table 8). Most of the razorback suckers released in a previous SY and contacted at the A10 upper spawn site were released in A10 upper or A10 lower (443 of 464; 95.5%), and 382 (82.3%) were only contacted in A10 upper during SY 2020. Razorback sucker larvae were observed at both spawning sites in February 2020.

Table 8.—Remote PIT scanning data for razorback suckers at the A10 upper spawn site, LCR, Arizona

Release location	Number of fish contacted	Mean days at large	Number of fish released in a previous SY
A10 upper	1,232	228	379 (81.6%)
A10 lower	268	164	64 (13.8%)
C7 McIntyre Park	38	163	12 (2.6%)
A7 upper	15	183	5 (1.1%)
C10 Ehler's	6	123	1 (0.2%)
Ehrenberg Bridge boat ramp	6	229	3 (0.6%)
Unknown (tagged at capture)	1	-	-
Totals	**1,566**		**464**

Remote PIT Scanning Antenna Orientation Study

During the first 4-day scanning period from February 24 to February 28, 2020, the eight PIT scanners collectively scanned for an average of 5,525 minutes (92.1 hours) per deployment and for 44,197 minutes. A total of 144 of 400 (36%) bonytail were contacted on orientation study scanners on the February trip; however, all bottom long deployments fell to bottom flat when the flotation became waterlogged, and there was no way to determine when their orientations shifted. As a result, data from the February trip could not be used to compare bonytail contact rates based on scanner orientation.

The second 4-day scanning period occurred from March 9 to 13, about 2 weeks after the experimental bonytail were released in A10 upper. During the March trip, each antenna was checked and data downloaded daily to ensure it was still in the proper orientation. The eight PIT scanners were deployed four times each and collectively scanned for an average of 1,367 minutes (22.8 hours) per deployment and for 43,738 minutes. Only 3 of 400 (< 1%) bonytail were contacted on orientation study scanners on the March trip. All three contacts occurred on bottom flat antennas. There was insufficient data to statistically assess scanner orientation via generalized linear modeling.

Bonytail A10 Upper Survival Study

Due to a malfunction of one of the culvert scanners 1 week after release, only data from the first 5 days after release were used to estimate bonytail survival. There were no contacts on the culvert scanners during this time, so no emigration out of A10 upper was assumed. The Cormack-Jolly-Seber top model based on the lowest AIC_c score was for constant survival (Phi) and constant contact probability (p), (table 9). The modeled estimate of daily survival for bonytail in A10 upper was 0.680 (95% CI 0.554–0.784). The daily contact probability was 0.332 (95% CI 0.237–0.443). The top model was not exclusively favored based on AIC_c model weights, so model averaging also was used for parameter estimation. Model averaging yielded similar estimates, with daily survival ranging from 0.638 to 0.704 and daily contact probability ranging from 0.310 to 0.333. The median c-hat estimate was not significantly different than 1 (0.882, 95% CI 0.587–1.119); therefore, c-hat was assumed to be 1 for model comparison and model averaging.

Population Estimates

No bonytail contacted in SY 2020 were released prior to SY 2020 (October 1, 2019), so no population estimate was possible. The razorback sucker population estimate for SY 2019 was 359 (95% CI 342—375), with 326 encountered in SY 2019 (marking period January through February 2019), 167 encountered in SY 2020 (capture period October 2019 through May 2020), and 152 encountered in both periods (recaptures). For comparison, the population estimates of

Table 9.—Results of bonytail survival parameterizations, LCR, Arizona and California
(N = 209 contact histories.)

Model	AIC_c	AIC_c weight	Number of parameters	Deviance
Phi(.) p(.)	464.5011	0.61751	2	17.125
Phi(t) p(.)	466.7847	0.19714	5	13.223
Phi(.) p(t)	467.0077	0.17634	5	13.446
Phi(t) p(t)	472.9562	0.00901	8	13.065

razorback suckers for the previous two SYs were 154 and 147 for SY 2017 and SY 2018, respectively. The population estimate for SY 2020 more than doubled compared to previous estimates likely due to inclusion of scanning data from the C7 gravel bar.

Post-Stocking Survival and Dispersal

Dispersal distances were calculated for acoustic-tagged fishes contacted outside their release backwater (tables 10, 11, and 12). Of the 50 fishes tagged this year, 28 were contacted outside their release backwater and 22 were only contacted in their release backwater (A10 lower and A10 upper are considered a singular complex here). Of the 28 fishes contacted outside their release backwater, 10 were adult razorback suckers, 13 were subadult razorback suckers, and 5 were subadult bonytail.

Table 10.—Dispersal statistics for acoustic-tagged razorback suckers released prior to SY 2020, LCR, Arizona and California
(Data are for fishes contacted outside of their release backwater after 3/22/2019 [last field day of SY 2019]. Tags 161, 163, and 165 are adult fish, and all other tags are subadults.)

Tag ID	Dispersal distance (km)	Location of last contact	Date of last contact
161	12.32	River at A7 upper	4/3/2019
163	18.54	River at Mule Wash	2/14/2020
165	78.93	River at Mule Wash	2/14/2020
186	29.65	A7 upper	3/30/2019
188	34.79	River at A7 upper	4/14/2019
194	8.68	River below McIntyre Park	4/6/2019
198	11.01	River at A7 upper	4/5/2019

Table 11.—Dispersal statistics for acoustic-tagged razorback suckers released in SY 2020, LCR, Arizona and California
(Days at large was calculated by the difference in days from the day of last contact and day of release. Tags 170-179 are adult fish, and all other tags are subadults.)

Tag ID	Dispersal distance (km)	Days at large	Displacement/day (km)
170	2.98	4	0.75
171	43.69	16	2.73
172	69.44	19	3.65
173	73.82	53	1.39
174	42.62	48	0.89
175	5.97	12	0.5
176	1.33	49	0.03
177	81.62	50	1.63
178	12.68	53	0.24
179	8.87	6	1.48
200	9.6	6	1.6
203	62.37	118	0.53
204	19.2	92	0.21
205	100.63	133	0.76
206	5.3	125	0.04
207	43.69	88	0.5
209	1.56	134	0.01
231	2.42	13	0.19
232	2	34	0.06
233	8.87	7	1.27
234	4.86	34	0.14
237	1.78	13	0.14
238	4.1	9	0.46

Table 12.—Dispersal statistics for acoustic-tagged bonytail released in SY 2020, LCR, Arizona and California
(Days at large was calculated by the difference in days from the day of last contact and day of release. All tags are subadults.)

Tag ID	Dispersal distance (km)	Days at large	Displacement/day (km)
210	1.56	8	0.2
213	28.54	26	1.1
221	43.69	3	14.56
225	43.69	12	3.64
229	8.2	23	0.36

All surgeries took place at the same location (A10 lower culvert). A similar rate of dispersal was observed this year, with 56% of implanted fishes leaving their release backwater, compared to 52% in SY 2019. Results were mixed for the 28 fishes that dispersed from their release location. The largest proportion of fishes (50%, 14 of 28) dispersed downstream; four of which were contacted by the furthest downstream SUR in the study area, south of Walter's Camp. Two of the 14 fish that initially dispersed downstream returned upstream in late January, went up and down the river between the SUR in the river at A7 upper and downstream from C7 during January and February, and then went back downstream later in February and March. The second largest proportion, 46% (13 of 28) were last contacted in A10 lower, C7 McIntyre Park, and the gravel bar area. Nine of these 13 fishes dispersed only a short distance after release, and the other 4 dispersed upstream and/or downstream before returning. Only one fish (4%) dispersed from its release backwater and had a last-recorded contact at a SUR upstream of its release area.

Several fishes from SY 2019 were contacted in SY 2020. Four adult razorback suckers from the January 31, 2019, surgeries were contacted after the end of SY 2019. One fish (tag 161) was last contacted on April 3, 2019, in the river at A7 upper, the second-most upstream SUR. One was contacted continually at A10 upper throughout the SY, with its last contact on March 4, 2020 (tag 162). Another fish was only contacted once in SY 2020, on February 14, 2020, in the river at Mule Wash. This fish (tag 163) was previously contacted in the river near Mule Wash via manual tracking on February 27, 2019. The last fish (tag 165) was contacted in the river at A7 upper in November, and then was continually contacted throughout January and February 2020 in the river at the C7 gravel bar, various points just upstream and downstream from the gravel bar, and at C7 McIntyre Park. Then, its last contact was further downstream in the river at

Mule Wash on February 14, 2020. Four subadult razorback suckers released with acoustic telemetry tags in SY 2019 were contacted after the end of SY 2019. The latest contact from this group of fish was fish 188 in the river at A7 upper on April 14, 2019.

The greatest calculated dispersal distance for a fish released in this SY was 100.63 km by a subadult razorback sucker released in October 2019. This fish dispersed from A10 lower, traveled downstream to C10 Ehler's in December, traveled up and down the river in January and February spending most of its time at the C7 gravel bar, but going as far downstream as Farmers Bridge and as far upstream as river at A7 upper, then went back to C10 Ehler's in early March. The cumulative dispersal average/median for all fishes released this year was 26.3/9.2 km; with 34.3/27.7 km, 20.5/5.3 km, and 25.1/28.5 km being the average/median calculated dispersal distances for adult razorback suckers, subadult razorback suckers, and subadult bonytail, respectively.

Four adult razorback suckers moved up and down the river often, all covering distances greater than 40 km (tags 171–174, 177; table 11). These fish went as far downstream as Farmers Bridge and as far upstream as the river at A7 upper. Most contacts (> 50%) for each of these fish were in the river around the C7 gravel bar. One adult razorback sucker (tag 171) was last contacted at the southernmost SUR at Walter's Camp on February 2, 2020 and may have dispersed out of the study area. The greatest calculated dispersal for bonytail was 43.7 km (tags 221 and 225; table 12). Both fish quickly traveled downstream to the southernmost SUR south of Walter's Camp shortly after release. These fish could have dispersed from the study area or may have died and floated downstream out of the study area.

Manual tracking effort resulted in contact with six fish in the main channel during SY 2020: five razorback suckers and one bonytail. Four razorback suckers were adults at the C7 gravel bar in the main channel outside of C7 McIntyre Park. The other razorback sucker and the bonytail were subadults contacted in the main channel downstream from C7 McIntyre Park and A10 upper/lower.

Scanning Probability Modeling

The scanning probability GAM analysis could only be completed for razorback suckers because very few bonytail were scanned in a SY after their release study year. For razorback suckers, TL and release location are significant predictors of monthly scanning probability, along with MAL and scanning month (table 13). In general, scanning probability was higher for greater TL (figure 9). For release location, scanning probability was highest for A10 upper releases, followed by C7 McIntyre Park and A10 lower (figure 10).

Table 13.—Model results for monthly scanning probability GAM for razorback suckers, LCR, Arizona and California

Parametric coefficients:	Estimate	Standard error	z value	Pr(>|z|)
Intercept (scan month = January, release location = A10 lower)	-5.26065	0.06019	-87.408	< 2e-16
Scan month:				
February	0.4667	0.04819	9.684	< 2e-16
March	0.22703	0.05376	4.223	2.41E-05
October	-2.48829	0.12859	-19.351	< 2e-16
November	-2.70716	0.1273	-21.266	< 2e-16
December	-1.30103	0.07307	-17.805	< 2e-16
Release location:				
A10 upper	1.36067	0.05229	26.02	< 2e-16
A7 upper	-1.07411	0.09429	-11.391	< 2e-16
C7 McIntyre Park	0.10666	0.07343	1.453	0.14634
DS of Ehrenberg Bridge	-1.60048	0.23508	-6.808	9.89E-12
C10 Ehler's	-0.64016	0.09963	-6.425	1.32E-10
Ehrenberg Bridge boat ramp	-0.41444	0.14309	-2.896	0.00378
Mayflower	-2.48969	0.45296	-5.497	3.87E-08
Oxbow	-3.66334	0.38192	-9.592	< 2e-16
Approximate significance of smooth terms:				
	edf	**Ref.df**	**Chi.sq**	**p-value**
s(MAL)	8.915	8.998	1536	<2e-16
s(TL)	6.107	7.019	1215	<2e-16
R-sq.(adj) = 0.0392 Deviance explained = 21.8%				
UBRE = -0.93215 Scale est. = 1 n = 425993				

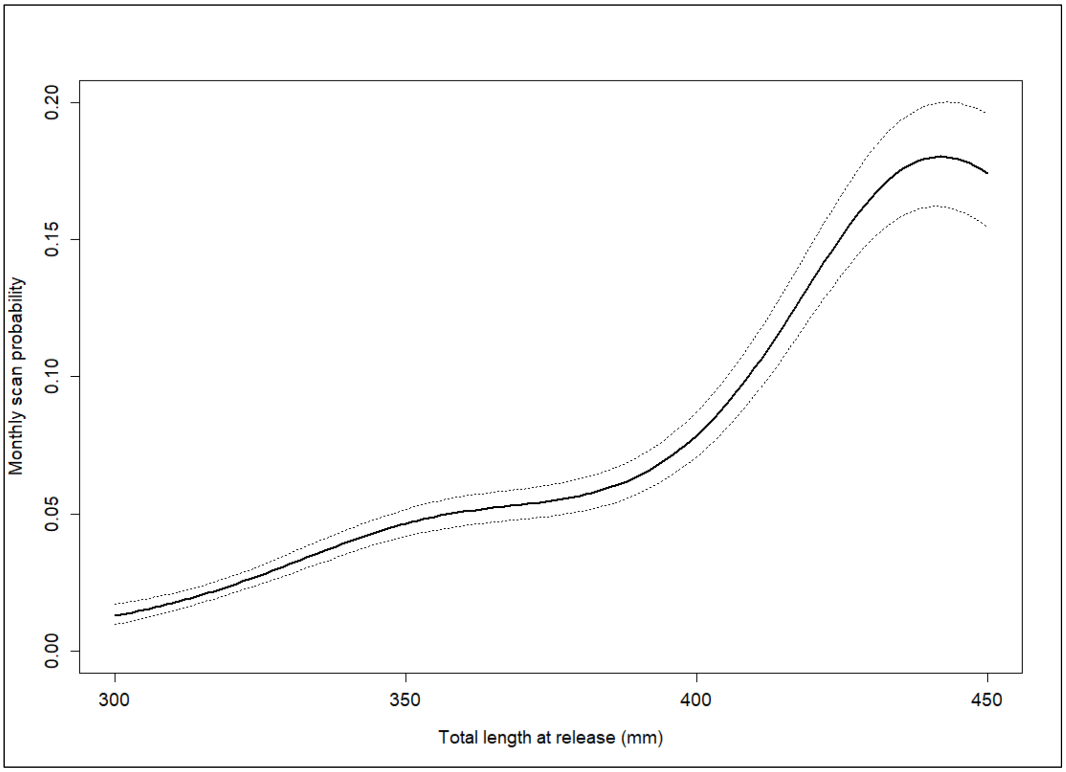

Figure 9.—Penalized thin plate regression spline from a GAM with 95% CI for the effect of TL (mm) of release on monthly scanning probability of razorback suckers, LCR, Arizona and California.
This graph is for the scanning month of January, MAL of 12, and release location A10 upper.

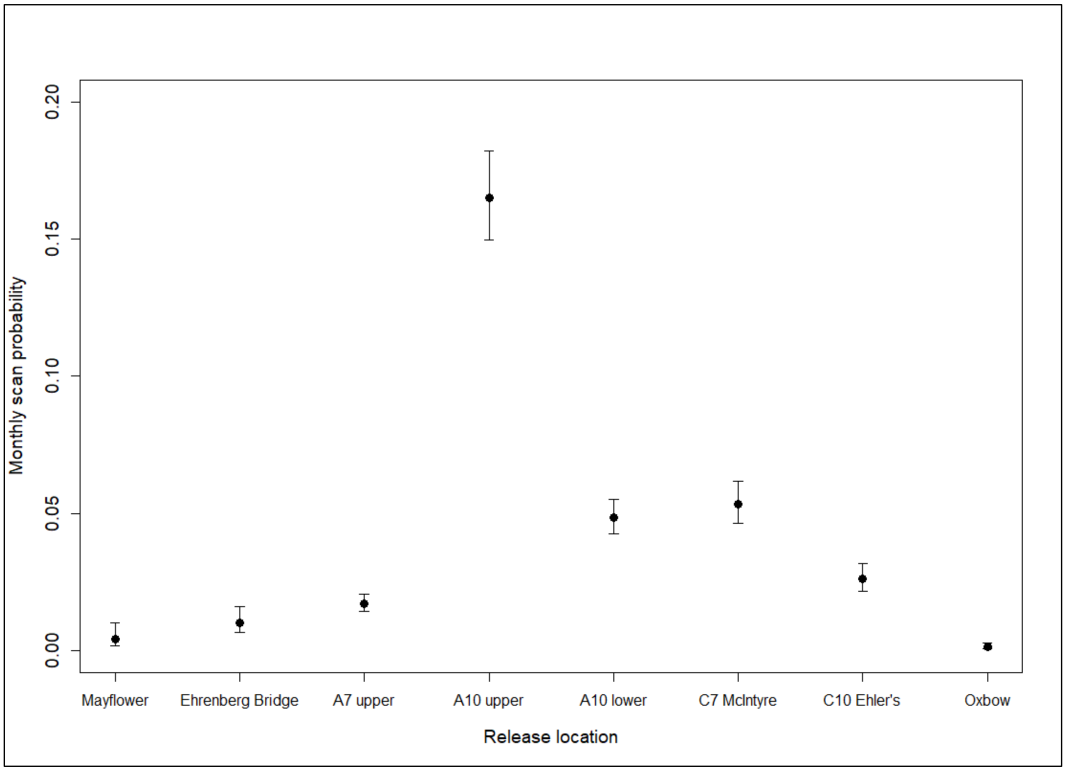

Figure 10.—GAM results for the effect of release location on mean monthly scanning probability (± 95% CIs) of razorback suckers, LCR, Arizona and California. This graph is for the scanning month of January, MAL of 12, and TL of 430 mm.

Adult Razorback Sucker Survival

The top robust model based on AIC_c score was for time-varying (SY) survival, time, and session varying contact probability (different contact rates for every sampling occasion), and no temporary emigration (table 14). Annual adult survival estimates from the top model ranged from 0.511 to 0.848 (table 15). Contact rates (probabilities) ranged from a low of 0.013 in October and December 2016 to a high of 0.801 in January 2019. All years had at least one occasion with contact rates above 0.50, with the highest values for each year occurring during peak spawning in January and February. Model averaging resulted in survival estimates of 0.548 from SY 2017 to SY 2018, 0.857 from SY 2018 to SY 2019, and 0.633 from SY 2019 to SY 2020; however, model averaging resulted in open CIs from 0 to 1 due to some of the models also having open CIs. Therefore, estimates from model averaging should be taken with caution.

Table 14.—Results of adult razorback sucker robust mark-recapture model parameterizations, LCR, Arizona and California
(N = 281 contact histories; table only includes models with AIC_c weights > 0.000001. There were 18 total models.)

Model	AIC_c	AIC_c weight	Number of parameters	Deviance
S(t) p(session:t) = c(session:t) γ'' (0) = γ'(0)	3833.562	0.699647	33	4747.502
S(t) p(session:t) = c(session:t) γ'' (t) = γ'(t)	3836.342	0.174265	36	4743.902
S(.) p(session:t) = c(session:t) γ'' (t) γ'(t)	3837.373	0.104071	36	4744.933
S(t) p(session:t) = c(session:t) γ'' (t) = γ'(t)	3840.505	0.021738	38	4743.792
S(.) p(session:t) = c(session:t) γ'' (t) = γ'(t)	3849.805	0.000208	34	4761.622
S(.) p(session:t) = c(session:t) γ'' (0) = γ'(0)	3851.953	0.000071	31	4761.622

Table 15.—Adult razorback robust mark-recapture model estimates of survival and contact probability, LCR, Arizona and California

	Interval	Estimate
Survival (S)	SY 2017 to SY 2018	0.511 (0.423–0.599)
	SY 2018 to SY 2019	0.848 (0.718–0.925)
	SY 2019 to SY 2020	0.581 (0.450–0.702)
Contact rate (p)	**Sampling occasion**	**Estimate**
SY 2017	October 2016	0.013 (0.003–0.051)
	November 2016	0.039 (0.018–0.085)
	December 2016	0.013 (0.003–0.051)
	January 2017	0.562 (0.462–0.658)
	February 2017	0.301 (0.228–0.386)
	February 2017	0.327 (0.25–0.414)
	March 2017	0.052 (0.026–0.102)
SY 2018	November 2017	0.041 (0.013–0.119)
	December 2017	0.014 (0.002–0.09)
	January 2018	0.502 (0.388–0.615)
	January 2018	0.176 (0.105–0.281)
	February 2018	0.596 (0.479–0.704)
	February 2018	0.258 (0.17–0.37)
	March 2018	0.217 (0.137–0.326)
SY 2019	October 2018	0.11 (0.064–0.185)
	November 2018	0.009 (0.001–0.062)
	December 2018	0.414 (0.325–0.509)
	January 2019	0.516 (0.422–0.608)
	January 2019	0.801 (0.714–0.866)
	February 2019	0.525 (0.431–0.617)
	February 2019	0.442 (0.351–0.537)
	March 2019	0.359 (0.274–0.453)
SY 2020	October 2020	0.078 (0.046–0.13)
	November 2020	0.042 (0.02–0.085)
	December 2020	0.228 (0.17–0.298)
	January 2020	0.336 (0.268–0.411)
	January 2020	0.45 (0.375–0.526)
	February 2020	0.468 (0.393–0.544)
	February 2020	0.696 (0.62–0.762)
	March 2020	0.588 (0.51–0.661)

Habitat Use

Habitat use was classified for telemetry fishes to assess relative use of backwater and riverine habitats (table 16). Subadult razorback suckers used main channel habitat to some extent (6 of 16; 37.5%), but the majority were contacted primarily in backwater habitats (15 of 16; 93.8%). Adult razorback suckers were the only group to have some individuals that were contacted primarily in river habitat (4 of 29; 13.8%). All subadult bonytail with habitat use data primarily used backwater habitats (11 of 11; 100%).

Table 16.—Habitat use characterization for telemetry fishes, LCR, Arizona and California

Habitat use category	Subadult razorback suckers	Adult razorback suckers	Bonytail
Backwaters	10 (63%)	8 (27.5%)	11 (100%)
Backwaters with periodic river	5 (31%)	9 (31%)	0 (0%)
River and backwaters	1 (6%)	8 (27.5%)	0 (0%)
River	0 (0%)	4 (14%)	0 (0%)
Excluded categories			
Never contacted	5	3	4
Only contacted in release backwater	39	1	61
Disappeared in main channel	18	7	12

DISCUSSION

A small but growing population of razorback suckers is developing in the Colorado River downstream from Palo Verde Diversion Dam. This population is reliant on stocking; no natural recruitment has been detected to date. Post-stocking mortality has not been estimated to date, but the probability of remote sensing (via PIT scanning) a razorback sucker post-release is correlated with size at release and release location. Preliminary estimates of adult survival in the study reach range from near the lowest in the Lower Colorado Basin, at 51.1%, to 84.8%, within the range of results elsewhere (e.g., 50.5–90.1% in Lake Havasu [Kesner et al. 2017]; 78% in Lake Mead [Rogers et al. 2019]; 91.7–98.5% in Lake Mohave [Miller et al. 2020]). There continues to be insufficient data available to analyze the bonytail population in the study reach because individuals are not detected beyond a few months post-release likely due to high post-stocking mortality.

The C7 gravel bar aggregation site was identified in SY 2019 and remained an important source of post-stocking contact data for razorback suckers in SY 2020. As in SY 2019, most of the adult razorback suckers (released in a prior SY) contacted at the C7 gravel bar were not contacted elsewhere during the SY. The inclusion of this distinct group had an immediate, positive impact on estimates of population size and post-stocking contact probability, as the SY 2020 population estimate is more than double the estimate from the previous year. Lack of encounters with these fish in the first two SY, likely introduced bias into analyses of all four years of data (e.g., robust mark-recapture estimates of survival). Therefore, estimates of razorback sucker adult survival in this report may be biased. Additional years with increased spatial coverage will increase accuracy of survival estimates.

Telemetry of adult razorback suckers thus far has provided little additional information on spawning behavior. None of the 20 adult razorback suckers tagged in SY 2017 and SY 2018 were active in the study area at the end of SY 2020. Of the 10 tagged in SY 2019, at least 5 likely were alive at the end of SY 2020. Two of these were captured during electrofishing at the C7 gravel bar in January 2020. Acoustic tags in both fish (tags 160 and 161) were inoperative despite being active for less than 1 year. It is unclear what caused these tags to stop working, but it brings into question whether other acoustic tags also failed well before the expected life of the tag. Two of the three adult razorback suckers tagged in SY 2019 that were contacted in SY 2020 made heavy use of river habitats and were last contacted downstream from study area backwaters. The third fish was continually contacted in A10 upper. Active tracking downstream from the main study area during peak spawning (January and February) may be conducted in SY 2021 to locate the few potentially surviving acoustic-tagged adult razorback suckers.

PIT scanners have been effective in contacting recently released bonytail within the release backwaters. However, long-term persistence of the species is still undocumented. Records of individual bonytail that survived a year or more are uncommon anywhere in open waters of the Colorado River Basin (Bestgen et al. 2017; Humphrey et al. 2016), and to date, there have been too few for a population estimate. Continued lack of detectable long-term persistence of bonytail suggests almost complete mortality of stocked bonytail shortly after release. Continuing experimental releases of bonytail with 32-mm HDX tags will provide further evidence of post-stocking fate for this elusive species. Bonytail are known to survive, reproduce, and recruit in captivity and in closed systems that lack predatory non-native fishes, so there are conservation management opportunities outside of the mainstream Colorado River (Osborne et al. 2018).

The effect of PIT scanner orientation on bonytail PIT tag contact rates remains unclear. Problems with maintaining antennas upright and rapid losses of stocked bonytail hampered efforts to provide conclusive evidence. Bonytail may shift from bottom oriented immediately after release to mid-water after acclimation, but this is only an issue if bonytail survive long enough to acclimate. A third attempt to evaluate potential for different antenna orientations to improve contact rates with bonytail may be conducted in SY 2021.

Additional sites in the river with aggregations of razorback suckers were not located in SY 2020 within the main study area. There is little evidence that razorback suckers emigrate out of the main study area. Two of 30 acoustic-tagged razorback suckers were contacted on the furthest downstream SUR (Walter's Camp) during SY 2020. Additional aggregation sites may still exist within the study area, and efforts to locate these sites will continue in SY 2021. The focus of SUR deployments in SY 2021 may shift further downstream to gate areas between C10 Ehler's and Walter's Camp. The area immediately upstream and downstream from the C7 gravel bar also will be gated with SURs to track movement of telemetry fish in and out of this area, and active tracking downstream from the main study area may be used during the peak spawning period to locate missing adult razorback suckers and potentially additional aggregation sites.

LITERATURE CITED

Akaike, H. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control 19:716–723.

Bestgen, K.R., R.C. Schelly, R.R. Staffeldt, M.J. Breen, D.E. Snyder, and M.T. Jones. 2017. First reproduction by stocked bonytail in the Upper Colorado River Basin. North American Journal of Fisheries Management 37:445–455.

Bureau of Reclamation. 2015. Native Fish Augmentation Plan, 2015–2020. Lower Colorado River Multi-Species Conservation Program, Boulder City, Nevada.

Cooch, E. and G.C. White. 2016. Program MARK: a gentle introduction. www.phidot.org/software/mark/docs/book/

Henne, J.P, M.M. Romero, and G.J. Carmichael. 2007. Polyculture of endangered bonytails and razorback suckers in recirculated water. North American Journal of Aquaculture 69:4, 388–394. DOI: 10.1577/A06-041.1

Humphrey K.G., B.R. Kesner, and P.C. Marsh. 2016. Distribution and post-stocking survival of bonytail in Lake Havasu. 2015 Final Report submitted to the Bureau of Reclamation, Boulder City, Nevada, by Marsh & Associates, LLC, Tempe, Arizona.

Karam, A.P., B.R. Kesner, and P.C. Marsh. 2008. Acoustic telemetry to assess post-stocking dispersal and mortality of razorback sucker *Xyrauchen texanus*. Journal of Fish Biology 73:1–9.

Kendall, W.L., J.D. Nichols, and J.E. Hines. 1997. Estimating temporary emigration using capture-recapture data with Pollock's robust design. Ecology 78:563–578.

Kesner, B.R., C.A. Ehlo, J.B. Wisenall, and P.C. Marsh. 2017. Comparative survival of repatriated razorback sucker in Lower Colorado River Reach 3, 2014–2016. Submitted to the Lower Colorado River Multi-Species Conservation Program, Boulder City, Nevada, by Marsh & Associates, LLC, Tempe, Arizona.

Laake, J. 2013. "RMark: An R Interface for Analysis of Capture-Recapture Data with MARK." AFSC Processed Report 2013-01. Alaska Fisheries Sciences Center, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, Washington.

Martinsen, B. and T.E. Horsberg. 1995. Comparative single-dose pharmacokinetics of four quinolones, oxolinic acid, flumequine, sarafloxacin, and enrofloxacin, in Atlantic salmon (*Salmo salar*) held in seawater at 10 °C. Antimicrobial Agents and Chemotherapy 1059–1064. May.

Miller, B.J., B.R. Kesner, C.A. Pacey, and P.C. Marsh. 2020. Demographics and Monitoring of Repatriated Razorback Suckers in Lake Mohave. 2015–2019 contract report submitted to the Lower Colorado River Multi-Species Conservation Program, Boulder City, Nevada, by Marsh & Associates, LLC, Tempe, Arizona, under contract No. R15PD00130.

Minckley, W.L. 1983. Status of the razorback sucker, *Xyrauchen texanus* (Abbott), in the Lower Colorado River Basin. The Southwestern Naturalist 28:165–187.

Mueller, G.M., P.C. Marsh, G. Knowles, and T. Wolters. 2000. Distribution, movements, and habitat use of razorback sucker (*Xyrauchen texanus*) in a lower Colorado River reservoir, Arizona-Nevada. Western North American Naturalist 60:180–187.

Osborne M.J., A.V. Sanchez, T.E. Dowling, and T.F. Turner. Variance in reproductive success is driven by environmental factors, not mating system, in bonytails. Transactions of the American Fisheries Society 147:1100–1114.

QGIS Development Team. 2017. QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org

R Core Development Team. 2018. RStudio: Integrated development environment for R (Version 0.96.122) [Computer software]. Boston, Massachusetts.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bulletin of the Fisheries Research Board of Canada, No. 191. Department of the Environment Fisheries and Marine Service. 382 p.

Rogers, R.J., B. Albrecht, and R. Kegerries. 2019. Razorback Sucker Studies on Lake Mead, Nevada and Arizona, 2018–2019 Annual Report. Submitted to the Lower Colorado River Multi-Species Conservation Program, Boulder City, Nevada, by BIO-WEST, Inc., Logan, Utah, under contract No. R15PD00015.

Schooley, J.D., B.R. Kesner, J.R. Campbell, J.M. Barkstedt, and P.C. Marsh. 2008. Survival of Razorback Sucker in the Lower Colorado River, Final Report. Submitted to the LCR MSCP, Boulder City, Nevada, by Arizona State University, Tempe, Arizona, under Agreement No. 06-FC-30-0002. 86 p.

Seber, G.A.F. 1973. The Estimation of Animal Abundance and Related Parameters. Griffin, London. 506 p.

Tyers, M. 2017. Riverdist: River Network Distance Computation and Applications. R package version 0.15.0. https://CRAN.R-project.org/package=riverdist

Tyus, H.M. 1987. Distribution, reproduction, and habitat use of the razorback sucker in the Green River, Utah, 1979–1986. Transactions of the American Fisheries Society 116:111–116.

Wood S.N. 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. Journal of the Royal Statistical Society (B) 73(1): 3–36.